Small Scale Wind Turbines: Alternative Power Supply Option for Construction Sites

By Kenneth Edem Agbeko

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University of Strathclyde

Department of Mechanical Engineering

Energy Systems Research Unit

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Abstract

Wind has been used for power generation dating back to several centuries. Wind is clean, free and inexhaustible. Advancements in wind power technologies has made wind energy one of the leading renewable energy sources available as the world continues in its search for alternatives to energy derived from fossil fuels.

Small scale wind turbines, which refer to turbines rated under 100 kW, have been used in many different applications. This makes them a potential power supply option for construction sites located in good wind regimes looking for cheaper and less polluting power supply alternatives.

The study looked at the use of small scale wind turbines as a supply option for the Xscape construction site at Braehead in Glasgow. The work involved a feasibility study and went on further to quantify the cost of energy, how much CO_2 savings would be made if such a system was in place as against the existing diesel powered generator system.

The study outcomes were that, one 15 kW Proven turbine (WT 15000) mounted at 30m should be used to meet lighting demands. The cost of energy if the proposed project was implemented would be 2.8p/kWh lower than the diesel supply option and would lead to 59 tonnes of CO2 emission savings.

Acknowledgements

I want to express my heartfelt appreciation to all individuals who have in one way or the other contributed to the success of this project and my studies.

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Contents

Appendix A

Appendix B

Appendix C

Appendix D

List of Figures

Chapter 2

Chapter 3

Chapter 4

Chapter 5

List of Tables

Chapter 1

Introduction

1.0 Introduction

Small scale wind turbines (turbines rated under 100kW) have over the years been used to power homes, small businesses and to meet the energy requirements of villages, cottages and telecommunication facilities in remotes locations without access to the grid around the world. These small scale wind turbines require cut – in speeds as low as 2.5m/s and rated speeds around 10m/s which are in most instances are readily available at most construction site locations.

With fuel costs escalating in recent years and environmental pollution a major important issue for policy makers regarding energy generation, the versatility of the small scale wind technology could be extended to the construction industry where diesel generators are the major source of power for onsite equipment and other needs.

One of the construction sites (Xscape) of Laing O'Rourke, a major international construction company, situated in Braehead in Scotland has been used as a case study for all the analysis of this study. The Xscape project is a ski-centre that has a shopping mall and car park building project valued at £50million. The study itself looked at meeting the lighting energy demands of the site accommodation cabins that has offices and a staff canteen with the energy supplied by a site mounted small scale wind turbine(s). At present it uses a 200 kVA diesel generator to meet its electricity needs with the fuel bought at a contracted price of 18p/litre. However that is to increase to about 27p/litre as from the beginning of next year which could see the company paying around 10.1p/kWh for electricity from the diesel generator. That would not be very affordable and hence the need to look at other alternative supply technologies.

Small wind turbines could be used to generate enough electricity to meet the lighting needs of the Xscape site and with the extra going towards heating and other electricity needs at a much cheaper cost per kWh. To achieve this however, siting would have to play an important part towards the overall maximisation of the available energy in the wind. Since velocity increases and turbulence decreases with height, the study looked at the possibility of mounting the turbine on top of the tower crane which usually could be as high 80meters. With power output directly proportional to the cube of velocity, crane – top mounting if all the technical and design considerations are catered for properly could prove to be a viable siting alternative and would greatly enhance the overall annual energy output from the turbine(s).

Spreadsheet modelling was extensively used for this study and the results represented in all sections have been taken from the turbine analysis and ecomonic appraisal models.

1.1 Aims & Objectives:

1. To conduct a technical feasibility study into the utilisation of the wind resource available on the Xscape site to provide power for the energy needs onsite.

2. To carry out an economic appraisal, quantifying the costs and return on investments for the utilisation of small wind turbines as a supply technology.
3. To outline the environmental impacts of the project with details on CO_2 emission savings.

1.2 Methodology:

1. ***Wind Resource Assessment***: Measured hourly wind speed and wind direction data for the Xscape site was collected for a four month period (from March to June 2005). The data obtained were then extrapolated to three (15m, 30m and 80m) intended hub heights for mounting for comparison using the power law.

2. ***Site Energy Demand:*** The energy demands of equipment and appliances onsite were then grouped into those needed for lighting, heating and others using their power ratings in kilowatts and the number of hours they are used to estimate the total energy demands daily and an annual estimate made.

3. ***Turbine Selection:*** Information gathered from the two previous tasks were then used in addition to an outlined selection criteria (including power output, cost and reliability) to select a turbine to supply power to meet the site's lighting needs.

4. ***Siting:*** Ground mounting and tower crane-top mounting were analysed as siting options.

5. ***Costing:*** The total lifetime cost was determined by estimating the annual loan repayments, overall operation and maintenance expenses, property tax and insurance for the design lifetime and expenses for reserving equipment parts and others in store for unexpected breakdown. This total lifetime cost was then used to estimate the cost per kWh of electricity generated from the turbines.

Chapter 2

Wind Power

2.0 The History of the Use of Wind

The motion of air with respect to the surface of the earth, which is generally referred to as wind, is basically caused by the variable solar heating of the earth's atmosphere. It is initiated first and foremost by the difference of pressure between points of equal elevation [1].

Wind has over the years been used to power sailing ships and in actual fact until the eighteenth century when James Watt invented the steam engine, it was the main source of power for these ships which inevitably discovered the whole world. Records date back to the seventeenth century B.C. when the then Babylonian emperor Hammurabi planned to use windmills for irrigation purposes [2]. A vertical axis machine with a number of radially mounted sails is also on record to have been used by the Persians extensively by the middle of the seventh century A.D [2].

Although these machines were crude and very inefficient, they go to prove the versatility and immense potential of the power from the wind. The twentieth century however saw wind power re-emerging as a vital resource that could be used as an alternative energy resource as the world faces the challenge of dwindling fossil fuel reserves and similarly as it becomes more environmentally conscious due to climate change [3]. These major challenges created the right climate for more research that has led to the development of more efficient devices to harness the power from the wind. A very significant transition worth mentioning is the use of steel and other composite materials such as fibreglass now as against wood as the dominant material in the early days. Electronics has also made a significant contribution towards the control of the turbines and has provided an efficient means of harnessing more power from the wind. The popularity of wind power has also increased as more wind resource assessments around the world indicate the availability of the resource for commercial utilisation in almost all countries. Thanks to all these advancements and discoveries, wind power has become almost competitive with the conventional coal fired and nuclear power generation methods today.

2.1 Wind Power Fundamentals

A wind turbine is a device that converts kinetic energy of the wind into electrical energy that can be harnessed for use. Windmills on the contrary convert the kinetic energy of the wind into mechanical energy and are mainly stand – alone systems used primarily for water pumping and grain grinding purposes. When a number of these wind turbines are installed in special configurations to generate several units of electricity they are then generally referred to as “wind farms”. Wind as an energy resource is clean, free and inexhaustible with the turbines needing far less maintenance as compared with conventional power stations [3]. Germany at present has the largest installed wind turbine capacity in the world. As of 2003, the total installed capacity was estimated to be 14,609

MW. In a typical wind year, Germany's wind farms generate enough to meet about 6% of the country's electricity needs, according to the German Wind Energy Association (Bundesverband Windenergie). Its wind energy industry also employs 45,000 people [4]. In the UK on the other hand, new installations grew by 103 MW in 2003 bringing the amount of wind power capacity to 649 MW, generating enough to power the equivalent of 441, 000 homes. More than 2000 MW of wind development are now permitted in the country with about half of that amount offshore [4]. Table 1 below give a summary of the top five world wind energy markets.

Table 1: Top five world wind energy markets

Top Five Wind Energy Markets (Installed Capacity in MW)	2002 Additions	2002 Year End Total	2003 Additions	**2003 Year End Total**
Germany	3247	12001	2645	**14, 609**
United States	410	4685	1687	**6,374**
Spain	1493	4830	1377	**6,202**
Denmark	407	2880	243	**3,110**
India	195	1702	408	**2,110**

Source: American Wind Energy Association (AWEA)

There are generally two main types of wind turbines namely, horizontal axis wind turbines (HAWT) and the vertical axis wind turbines (VAWT) with the former far more common. HAWT refers to a turbine whose rotor axis is parallel to the direction of the wind stream and the ground. They are commonly classified according to the rotor orientation (upwind or downwind) of the tower, hub design (rigid or teetering), rotor control (pitch or stall), number of blades and finally their alignment with the wind (free yaw or active yaw). A VAWT on the other hand is one in which the direction of the wind stream and the ground are perpendicular to the rotor's rotational axis.

HAWT and VAWT basically vary on grounds of their axis rotation and self starting ability among many others but have similarities regarding components. The common components to both horizontal axis and vertical axis wind turbines are; the rotor (comprising the blades and supporting hub), the drive train (comprising the shafts, gearbox, coupling, braking system and generator), the nacelle and main frame, the tower and its foundation, the machine controls and general electrical system (including cables, switchgear and transformers) [5].

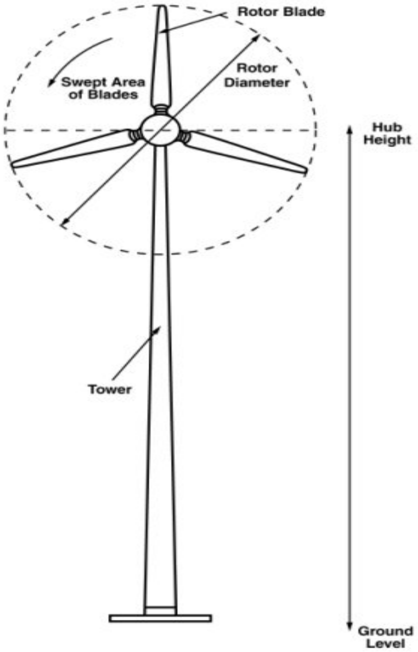

Figure 2.1 Wind turbine schematic (Source: Clarke, S., Electricity generation using small turbines at your home or farm)

The amount of power that can be harnessed from the wind is a function of the air density (ρ), turbine blade area intercepting the wind (A), and the instantaneous wind speed (V) as shown in equation 2.1.1.

Power, $P = 0.5Cp.\rho.AV^3$ (2.1.1)

Where:

Cp = Coefficient of Performance

ρ = Air density (kg/m^3)

A = Swept area of rotor blades (m^2)

V = Wind Speed (m/s)

Any variation in the above mentioned parameters will either lead to an increase or decrease in the power harnessed. As stated, an increase in any one of the parameters will lead to an increase in power output but wind speed which is the rate at which air flows past a point above the earth surface is seen as a very important parameter as it is a cubical function. That is to say doubling the wind speed will lead to the power increasing by a multiple of eight. However this does not come about easily as wind speeds vary randomly with time. This random variation is due to the turbulence of the of the wind flow which is often caused by obstacles such as, trees, hills, valleys or buildings around. Turbulence intensity decreases with height and so wind turbines are mounted on high towers to escape regimes of high turbulence.

Perhaps the second most important parameter is rotor swept area, which refers to the turbine blade area intercepting the wind. By the doubling the area you double the power. This circular area swept the rotor blades can be computed using the area of a circle given in equation 2.1.2 below.

Area, $$A = \frac{\pi D^2}{4} \tag{2.1.2}$$

Where:

π = Pi (Constant)

D = Rotor diameter (m)

Thus by increasing the rotor diameter by 30 percent (for example from 3m to 3.9m) you can increase the swept area by nearly 70 percent (actually 69% from $7.07m^2$ to $11.95m^2$).

Air density on the other hand varies with temperature and elevation and therefore since warm air is less dense than cold air, power outputs are expected to be lower in the summer than in the winter if all the other parameters were to stay the same. At standard conditions (sea level, 15^oC) the density of air is 1.225 kg/m^3. The graph in figure 2.2 shows the variation of density with elevation.

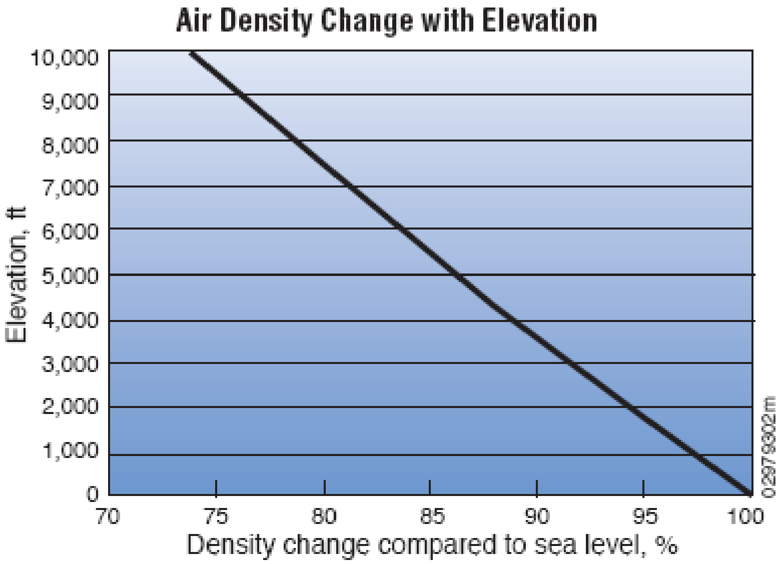

Figure 2.2: Changes in air density with elevation (source: US Department of Energy)

Power output is calculated using a constant Cp (power coefficient). However, Cp is a function of blade tip speed and pitch angle. Blade tip speed varies with wind speed, and the blade pitch angle is variable for pitch regulated turbines. It is however worth nothing that there are practical limitations to the amount of energy that can be extracted by these turbines. For an idealised turbine without losses, the power coefficient, Cp, equals to the Betz limit (Cp = 16/27).

Using these parameters, a power curve can then be obtained for a given turbine to predict how much energy it can generate without considering the technical details of its various other components. A typical power curve like the one illustrated in figure 2.3 has a:

- Cut - in speed which is the minimum speed at which the turbine will begin to deliver power.

- Rated speed which is the speed at which the maximum power output from the turbine is reached.
- Cut – out speed which refers to the maximum wind speed the turbine is allowed to deliver power, beyond this speed the turbine is shut down or regulated to furl or turned from the wind.

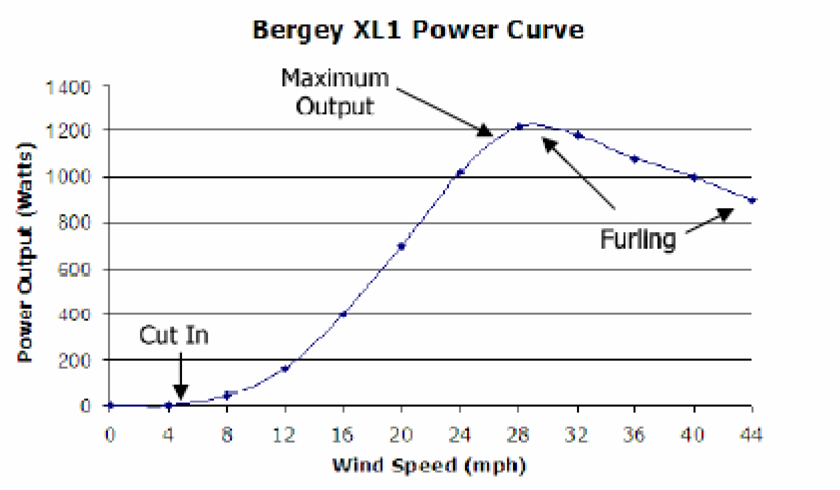

Figure 2.3: A typical power curve for a small wind turbine (source: kidwind project, 2004)

2.2 Small Scale Wind Power

Over the years, many homes have resorted to generating their own electricity to compliment power received from the grid or because their homes are in remote location and therefore have no access to the grid. Diesel generator systems and solar PV systems have been the preferred or common options. However, with "miniature" wind turbines now readily available on the market, small scale wind power systems are growing in popularity.

Small scale wind turbines refer to wind turbines which are typically rated below 100 kW with rotor diameters between 0.58m and 6.4m, and mounted on towers of height between 19.8m and 36.6m [6]. A typical household's annual electricity demand of about 10,000 kWh on a site with an average wind speed of about 5.5m/s can be met using a 6 – 15 kW rated turbine. Excess generation can even be fed into regional distribution lines and thereby strengthening the existing electricity grid and further providing additional income to the individual households. Thanks to the successes achieved by the large commercial wind turbine industry, significant advances have been made in the design of small wind turbines thus making them more reliable, quieter and safer than those introduced in past decades [6].

As of 1997, T. Forsyth, P. Tu and J Gilbert had found 55 small turbine manufactures (8 US and 47 international) offering 146 different turbine models (23 US and 123 international) in their research. Furling or tilting up out of wind and passive blade pitching were reported as the most commonly used overspeed control techniques accounting for 39% and 36% respectively of the turbines surveyed. The remaining 25% use fixed – pitch stall regulating technique. It is equally worth noting that most of the turbines either had a mechanical or electrodynamic braking system or had manual furling capabilities [7]. Some of the major manufacturers of small scale wind turbines around the world are; Proven Energy, AmpAir and Renewable Devices (in the United Kingdom), Bergey Windpower Company and Wind Turbine Industry (in the United States of America), Westwind Turbines (in Australia) and Vergnet S.A. (in France).

2.3 Small Scale Wind Turbine Configuration

Small scale wind turbines generally consist of a rotor with blades, a generator, a tower and electrical system (wiring, controllers, inverters and/or batteries). Like large wind turbines, small scale wind turbines are available as either horizontal or vertical axis types and single or multiple bladed types. Three bladed - horizontal axis types dominate this market too. Generally turbines with three blades run more smoothly than two bladed ones. Vertical axis wind turbines on the other hand have been unpopular because although they do not need a tower saving you money, wind speeds very close to the ground are very low meaning low overall power outputs. Similarly although they do not need a yaw mechanism to turn them into the wind because they receive wind from any direction, they are not self starting and therefore require drawing of power from the grid to start the machine.

2.3.1 Turbine Blades

Turbine blades are the devices that convert the force of the wind into the torque needed to generate useful power. These blades are designed to have shapes which are determined by the overall layout of the turbine, aerodynamic considerations, material characteristics and available methods of fabrication.

The power that can be extracted itself is a function of the time (t_b) for one blade to move into the position previously occupied by the preceding blade, as compared with the time (t_w) between the disturbed wind moving past that position and the normal airstream becoming re-established. This time t_w varies with size and shape of the blades and inversely as the wind speed as shown in equation 2.3.1.

$$t_w = \frac{d}{v} \tag{2.3.1}$$

Where:

d = distance (a measure of the length of the strongly perturbed air stream upwind and downwind incident on the blade)

v = speed of the oncoming wind

Hence if blades are too close together (that is the blade following the other moves rapidly into the turbulent air created by the preceding blade) or too far apart (that is air passes through the cross-section of the rotor without interfering with blades whiles rotating), power extraction efficiency will decrease [8].

Turbine blade root stresses increase with the number of blades for a turbine of a given solidity. Three bladed turbines run smoothly even while yawing because their polar moment of inertia with respect to yawing is constant and is independent of azimuthal position of the rotor. They also represent a fair compromise between a technically sound design option and cost effectiveness. For these reasons and many others, three bladed turbines have become the most common design choice for small wind turbine manufacturers although others still use two (e.g. Bornay Inclin, Whisper H175 and Eoltec Scirocco models), one and even multiple blades (e.g. Swift).

Small turbine blades are mostly made from composite materials such fibreglass, polypropylene and carbon fibre. These composite materials have the advantages of having a high strength and high stiffness to weight ratio. In addition, they are corrosion resistant, are electrical insulators and lend themselves to a variety of fabrication methods. Wood has a good strength to weight ratio and is especially good in fatigue. According to a US National Research Council assessment research report on wind turbine rotor materials in 1991[9], no wood - epoxy blade has ever failed in service due to fatigue. Thus, small wind turbine models like Proven Energy's WT 6000 which use wood – epoxy are equally as good as the others which use the more fancied fibreglass and other composite materials.

2.3.2 Orientation

Figure 2.4 Bergey XL.1

Almost all small horizontal axis wind turbines use a tail vane to direct it into the wind. Tail vanes are used instead of yaw motors and mechanical drives whose sizes cannot be accommodated in the small wind turbines. Figure 2.4 shows a typical three bladed small wind turbine with a tail vane.

2.3.3 Overspeed Control

Although invariably higher speeds mean more power, strong winds can damage the turbines. To prevent damage to the turbines in extreme wind conditions and for the safety of people in its neighbourhood, small wind turbines have overspeed mechanisms in place. The common overspeed control techniques in use by small turbines are; furling (horizontal and vertical), pitching and a combination of furling and pitching.

To furl, the rotor axis is offset from the furling axis. During furling, the rotor swings horizontally or vertically towards the tail vane. Bergey Windpower Company’s turbines like the XL1 shown in figure 2.4 furl horizontally, whiles others like the Windseeker and Whisper made by Southwest WindPower and World Power respectively, furl vertically.

‘Pitching is used to describe the mechanism of turning the rotor blades slightly out of the wind when the wind speed exceeds certain limits or power output becomes too high. The rotor blades turn about their longitudinal axis in a way so as to waste part of the energy available in the wind. When conditions normalise, the blades are turned back into the wind to fully extract the available energy according to the turbine’s capability and generator rating [10]’.

2.3.4 Generators of Small Turbines

Small turbine manufacturers mostly turn to use permanent magnet generators. With permanent magnet generators, there is no need for field windings or supply of current to the field as the generators themselves provide the needed magnetic field.

Permanent magnet generators are asynchronous machines and are therefore not connected directly to an alternative current (AC) network. This is because the power produced initially by these generators, have variable voltages and frequencies. To utilise the power produced for battery storage or direct current (DC) load applications, the AC produced is rectified to DC immediately, or otherwise inverted to AC with fixed voltage and frequency for grid connection.

Some small turbine manufacturers like Bergey WindPower Company and World Power have their generators designed such that the permanent magnets are attached to the casing (magnet can) which rotates outside the stator (which is the stationary part of the generator). This makes it possible for the rotor blades to be bolted directly to the case.

2.3.5 Small Wind Turbine Towers

Small wind turbines like large wind turbines use towers to elevate the main part of the machine into the air. These towers represent a trade-off between increased energy capture and increased cost. They should be high enough to ensure the tips of the turbine blades do not touch the ground and be equally strong enough to withstand the forces induced by the wind at higher altitudes.

Towers for small wind turbines are classified into three categories based on their structural configuration as [11]:

- A guyed towers
- A free – standing truss or lattice type tower and
- Monopoles (free - standing tubular tower)

Guyed towers use a lattice, pipe or tubing tower section and are the least expensive. They are normally guyed in three directions over an anchor radius of typically 2/3 of the tower height and have a triangular section for the central mast. Guyed towers therefore require a large free space to anchor guy wires. They can also be hinged so they could be easily lowered and raised and for maintenance purposes.

The tubular monopole type on the other hand, has the advantage of being more aesthetically pleasing especially if tapered but turn out to be the most expensive. Proven Energy, a UK small turbine manufacturer, uses tubular towers for its turbines. For example the 15m tower for its 15 kW turbine is 608mm and 354mm in diameter at the bottom and top respectively, made of galvanised steel and costs £8,000.

A primary consideration in these tower designs and selection is the impact of the tower's overall stiffness on its natural frequency. This is to ensure resonance excitation in the rest of the turbine does not occur. The natural frequency of a tower can be determined by modelling the turbine and tower structure as a cantilever with a point mass on the top. Baumeister's derived equation [12] given here as equation 2.3.2 can then be used to determine the natural frequency.

$$f_n = \frac{1}{2\pi}\sqrt{\frac{3EI}{(0.23m_{Tower} + m_{Turbine})L^3}} \tag{2.3.2}$$

Where:

f_n = Fundamental natural frequency (Hz)

E = Modulus of elasticity

I = Moment of inertia

m_{Tower} = Mass of tower (kg)

$m_{Turbine}$ = Mass of turbine (kg)

L = Height of tower (m)

Towers are also classified as also stiff or soft. Stiff towers have their natural frequencies higher than that of the blade passing frequency (given by the product of rotor's rotational speed and its number of blades). Whereas soft towers have their natural frequencies lower than the blade passing frequency and also below the rotor frequency. Soft towers are generally less expensive than stiffer towers [13].

Foundations are constructed usually with reinforced concrete to keep the tower upright and stable under the extreme design conditions. However to reduce cost and to promote small and micro wind turbines, some researchers and manufacturers have been considering and utilising roofs of building as an alternative to high towers. Renewable

Devices in Edinburgh, UK is one such developer and has by far been the most successful with its award winning Swift wind turbine design (rated 1.5 kW) [14].

The impact of wind forces on towers also places a limitation on the height of these towers. The wind force on a tower can be computed from equation 2.3.3

$$F = 0.6C_f A_e V^2 \tag{2.3.3}$$

Where:

C_f = Force coefficient

A_e = Effective projected area

V = Wind velocity at height Z (m/s)

2.3.6 Small Wind Turbine Loads

Forces that act on structures such as turbines are called loads. Turbines would have to be able to withstand the loads that would be imposed on them during their operation else they would fall apart and therefore makes turbine loads a major consideration during their design. In the utilisation of these turbines also, consideration must be made with regards to what loads are likely to be imposed on them in the location chosen for siting and whether they would be within acceptable design limits.

Turbine loads can generally be organised into five categories; steady, cyclic, stochastic, transient and resonant – induced loads. The sources of these loads are shown in the figure 2.5 [13].

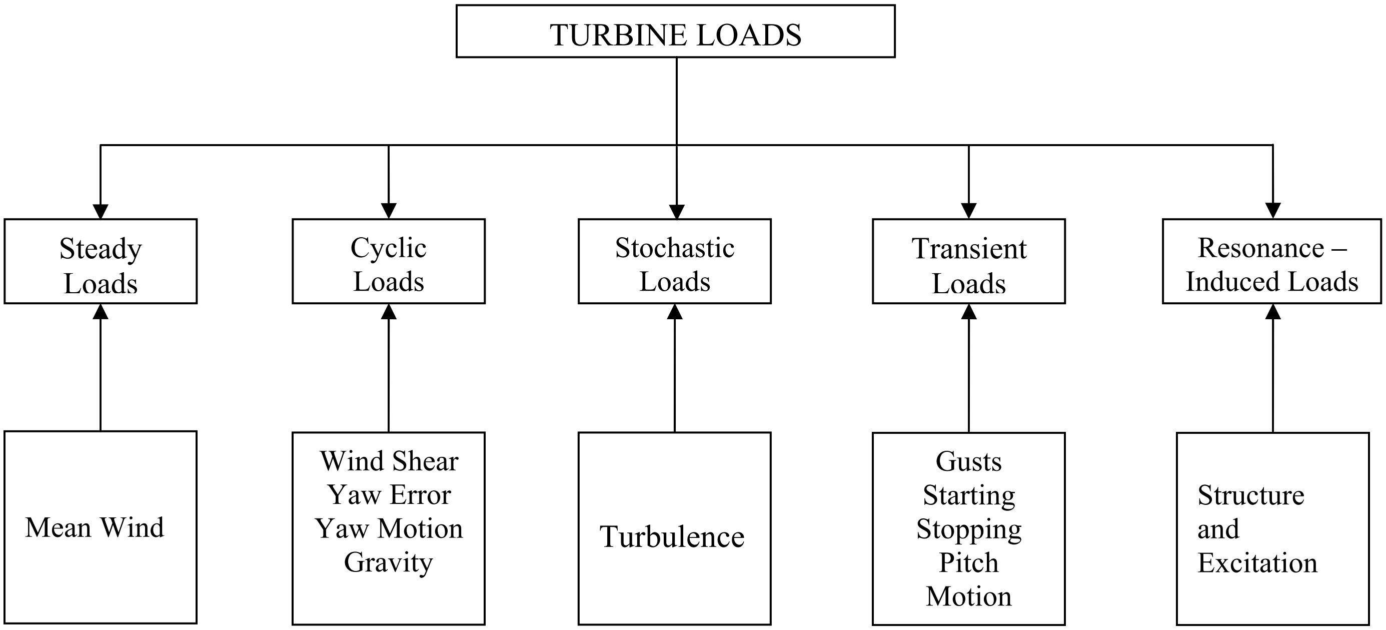

Figure 2.5 Sources of wind turbine loads (Source: Manwell, J. F., et al Wind Energy Explained)

2.4 Utilisation of Small Wind Power

Small wind turbine systems have generally been utilised in many applications if [15]:

- The location has a good wind resource
- The site is at least 1 acre in size
- The local ordinances allow wind turbines
- Electricity bills for the property turn to be high
- The property does not have access to the utility grid
- The user is comfortable with long term investment

- Turbines could be mounted 250 – 300m away from the property of the nearest neighbour

Small wind turbine systems have found their major applications when all or most of the conditions above have been met over the years to primarily:

- Power remote homes
- Pump water for agricultural and livestock needs
- Partially or completely displace utility grid power
- Charge batteries for onwards use

Specific instances where different small turbines have been utilised are listed in chapter five.

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Chapter 3

Demand Profile

3.0 Overview of Laing O'Rourke Construction Company

Laing O'Rourke is an international construction group that specialises in the design and building of large construction projects. The Laing O'Rourke Group was founded in 1977 by its current chairman Ray O'Rourke and presently has a workforce of about 16,000 worldwide and 9,000 here in the UK [1].

It entered the Scottish marketplace in 1993 and in October 2001, Laing Construction was purchased by the O'Rourke Group with a new holding company, Laing O'Rourke plc formed in the spring of 2002. This led to the re-branding of its Scottish construction operations as Laing O'Rourke Scotland Limited (LORS). The company has ever since been experiencing tremendous growth in its annual turn over, reaching £1.6billion in 2004 [1].

Laing O'Rourke continues to strive to be the first choice for all its stakeholders and is changing the poor quality image of construction worldwide, by always introducing new design innovations and bringing on board the latest construction techniques to all its projects.

The Laing O'Rourke Group is further structured into three major sub-groups namely services, construction and products. Figure 3.1 below shows the overall company structure.

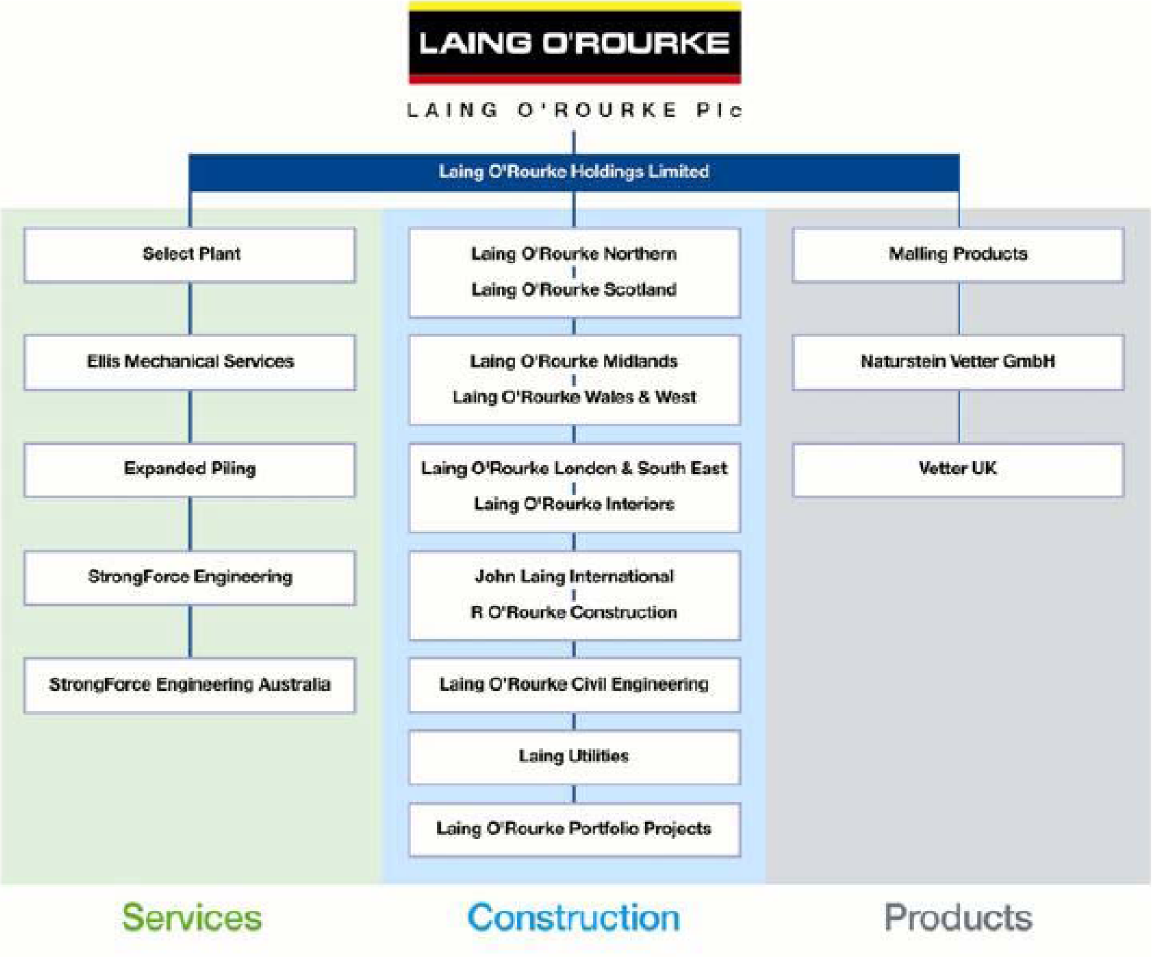

Figure 3.1: Laing O'Rourke Organisation Structure (Source: Thomson S., "Laing O'Rourke & ISO 14001").

Below are examples of fully completed projects by Laing O'Rourke here in Scotland.

Figure 3.2: Buchanan Galleries, Glasgow (Structures and Department Store fit – out £67m)

Figure 3.3: Edinburgh Airport Car Park (Value £19.8million)

The next set of on-going projects it is undertaking in Scotland is listed in descending order of contract value as follows:

- Xscape Snow dome (£50million)
- Air Traffic Control Centre at Prestwick (£30million)
- Canniesburn Residential Development (£27.6million)
- Strada Residential Frames Blocks (£2million)
- Renfrew Council Headquarters Work Package (£1.5million)
- Glasgow Royal Infirmary Car Park

Although already an ISO 14001 accredited company, it is continually striving for improvements in its environmental performance. The utilisation of small wind energy systems is a further step it is taking to reduce carbon emission in an effort to meaningfully contribute towards the fight against climate change and global warming.

3.1 Overview of the Xscape Project

The Xscape project is the construction site used for this study. It is a state of the art building project being developed near Braehead shopping complex, located on the south bank of the River Clyde in Glasgow, Scotland. When finally completed, it would comprise a ski-centre with a dry ski slope, a cinema and shopping malls with car parking and gardens and has a total estimated project value of £50million. The on-site workers are mainly building contractors, technicians, supervising engineers and company management staff. A two-storey accommodation cabin has been provided on site for staff use.

3.2 Related Work Done to Date

Laing O'Rourke as a company is aware and constantly putting together plans to control and manage energy consumption on its construction sites. It is in line with this desire that the company is working with the Carbon Trust to find methods of reducing energy consumption. To effectively management and monitor energy consumption on site, it has assigned one mechanical and electrical (M&E) engineer to be in charge of energy management. The M&E engineer has been using the Xscape project site to try out many energy efficiency measures and as it stands the Xscape project site has the best energy efficiency practices witnessed on four sites visited by David Palmer of Campbell Palmer Partnership Ltd in a related work done by him. In Mr Palmer's recommendations he emphasised that the Xscape project site should be as the basis of a Laing O'Rourke procedural document for energy conservation on current and future Laing O'Rourke construction sites. He however further recommended training in energy management and energy technologies to allow the M&E manager to build on his knowledge of the subject, and to develop appraisal skills for investment opportunities [3].

On the actual work done by Mr. Palmer, he [3]:

- Identified key energy efficiency issues for Laing O'Rourke

- Undertook energy audits for four Laing O'Rourke construction sites including the Xscape project site
- Provided an outline specification for energy efficiency prefabricated cabins.

Although his work centred on energy efficiency, he was quick to point out the implication of using diesel generators which produce up to twice as much CO_2 as compared with electricity drawn from the grid. With the CO_2 emissions from the national grid in the UK estimated to be 0.43 kg/kWh, diesel generators operating at maximum efficiency of 35% liberate 0.71 kg/kWh and are even worse off when operating at mean load of 20% and 27% efficiency. The four sites Mr Palmer audited were all operating around the mean load implying that they were each liberating 0.93 kg of CO_2 per kWh of electricity generated.

Three colleague MSc. Students at Strathclyde University conducted a demand side management group project of which one of Laing O'Rourke's construction sites (National Air Traffic Control site at Prestwick) was used. In their work, they looked at shifting loads to match supply from a renewable energy source. Solar PV was used as the supply option for the estimation instead of wind power because of the strict regulations on the use of high rise structures that could affect communication equipment at the airport. In their modelling results for the site cabins, they arrived at an optimum 10 W/m^2 for energy consumption in the cabins if the room temperature is regulated to stay between 18^oC and 21^oC [4].

3.3 Site Demand Profile

Electricity is required to power all the appliances used in all the rooms, corridors and out – door locations on site. Specifically, electricity is used for lighting, water heating, office and catering equipment in the accommodation cabins. The two storey cabin accommodation facility on site, houses 16 offices, a large canteen and kitchen, toilet, drying room, 9 jackleg rovacabins and an induction cabin used by subcontractors.

Construction plant equipment use the bulk (75 – 80%) of the power supply on the site and the rest goes into mainly lighting and heating over the winter period. Electricity is required for the entire ten and a half working hours (0730 – 1800) on site, five days a week (Monday – Friday).

3.3.1 Detailed Demand Profile for Accommodation Cabins

An energy audit had previously been conducted as part of Mr. Palmer’s contracted work on the Xscape site within the last three months before the commencement of this study. With nothing having really changed after the completion of his work, the data collected were assumed to be valid and reflective of the energy consumed in each cabin and therefore used for the demand analysis in this study.

All the 16 offices, the reception, corridors and toilets, on the Xscape site are fitted with 4ft fluorescent lamps rated at 36 W with the average number in each office being 2 for lighting needs. In addition, each office has office equipment including laptops (150 W), TFT monitors (34 W) and VDU (300 W).

There is a water heater in the kitchen rated at 3000 W and all other space heating is provided by electric convector heaters rated at 2000 W. On – Off switches are used to control the electric heaters in the offices and thermostats for those in the drying room and toilets. The detailed cabin to cabin energy consumption can be found in Appendix A.

For this study, a worst case scenario is used for computations. That is, it is assumed that 80% of the lighting is on 52 weeks for 12 hours per day, 5 days per week and 50% of the heating is on during the winter season lasting 26 weeks for 12 hours per day, 5 days a week. A summary of the heating, lighting and other energy demands for the Xscape site is presented in table 2 below.

Table 2: Xscape Site Energy Demand Break Down

Energy Utilisation	Total Appliance Rating (kW/day)	Daily Energy Consumption (kWh/day)	Annual Energy Consumption (kWh/year)
Lighting	8.03	77.09	20,042.88
Heating	101.2	607.20	78,936.0
Others	15.172	145.65	37,869.0
Total Demand	**124.40**	**829.94**	**136,847.88**

3.4 References:

[1] Laing O'Rourke, Who we are, URL http://www.laingorourke.com

[2] Thomson, S., Laing O'Rourke Scotland and ISO 14001, 2004

[3] Palmer, D., Restricted – Commercial Partnership Report for Laing O'Rourke Scotland, Document Reference SRV 13892.1, Pg 3, April 2004.

[4] Walker, A., et al, Demand Side Management, Student Group Project, University of Strathclyde, 2004.
URL: http://www.esru.strath.ac.uk/EandE/Web_sites/04-05/demand_side_management/index.htm

Chapter 4

Supply Profile

4.0 Existing Supply Technology on Site

A 200 kVA diesel engine connected to a generator set supply the Xscape site with the needed electrical power which is occasionally loaded at 34%. An additional 27 kVA generator has been provide to supply electricity for temporary lighting needs and also serves as the power source for the power tools used by sub – contractors.

At present, Laing O'Rourke has a signed contract with its supplier that makes it possible to buy fuel at 18p/litre. However when a new contract comes into place starting January 2006, the new contract price would be pegged around 27p/litre meaning the cost of electricity would rise to 10.1p/kWh from its current cost of 6.66p/kWh.

In spite of the high cost of energy from this supply system, they are well proven and highly dependable if well maintained.

4.1 Why Utilise Wind Power on-site?

Diesel generators as a supply technology have worked reliably over the years for Laing O'Rourke. Although the national grid offers a cheaper supply option, more often than not construction sites in remote locations do not have access to grid electricity and therefore diesel generators become the most convenient supply option.

However as fossil fuel reserves continue to decline, fuel prices continue to increase. Additionally legislations concerning CO_2 emissions are becoming stricter.

Recent advancement in small wind turbine technologies make them a potential supply option for construction sites located in good wind distribution regimes. Their estimated design lifetime of 20 years also means they could be dismantled and moved to new construction sites when projects are completed at one site. This implies, they would be utilised well enough, pay for themselves and bring in additional returns on the initial capital investment.

4.2 Wind Resource Assessment

The amount of power that can be generated by a turbine to a large extent depends on the average wind speed at the proposed site. Because power output is proportional to the cube of the wind speed, any small change in wind speed affects the power output significantly. For this reason, it is important to measure the wind speed on any proposed site to facilitate a better estimation of how much power can be harnessed.

Commercial wind power developers typically measure actual wind resource, to determine the distribution of the wind speeds for a full year. Where this is not practical for various reasons such as cost or time constrain wind speed distributions at a nearby meteorological station are used. The data gathered are then extrapolated to the proposed hub height.

In some cases however, both sources of useful data acquisition may be unavailable. In that case, statistically - based methods of resource assessments such as the Rayleigh (Chi-II) or the Weibull distribution functions are adopted as useful estimation tools.

Wind researchers over the years have compiled these measured and estimated data for a number of locations around the world and developed them into wind resource atlases. These atlases can equally be relied on but it must be emphasised that other than the US and European atlases, the others have not as yet been fully developed and do not have enough data and hence not that accurate. A number of laboratories and agencies such as the National Renewable Energy Laboratory, Sandia National Laboratory, the United States Department of Energy and many others in Europe are providing technical assistance in this direction to developing countries to undertake wind resource assessments so as to develop more reliable wind atlases for their respective countries and regions.

4.2.1 Wind Measurement on-site

Instrumentation for wind resource assessments contribute immensely towards the accuracy and reliability of the data gathered. The meteorological station set up on the

Xscape site measures wind speed, wind direction, ambient air temperature and air pressure using a cup anemometer, wind vane, thermometer and barometer respectively. The cup anemometer which measures wind speed operates on the principle of the transfer of momentum. The anemometer rotates proportionally to the speed of the prevailing wind to generate a signal. These signals are picked up by an electronic data logger. Typically cup anemometers have accuracy values of about ±2%. Their reliability is affected by environmental factors such as icing or dust which do lodge in the bearings. This increases friction in the bearings and thus reducing wind speed readings. Regular calibration is a good way to offset this problem [1].

Figure 4.1: Xscape weather station

The cup anemometer on the Xscape site is on a 6m high tower as shown in the picture in figure 4.1. The anemometer is connected to a data logger (see figure 4.2) from which data we onto a computer.

Figure 4.2: Davis Wind Data Logger

4.3 Wind Data Processing

Four months data (March – June 2005) from this on-site meteorological station was collected and processed for the supply estimation done in this study. The data collected at the measured height (6m) were extrapolated to 15, 30 and 80 meter heights using the power law (equation 4.4.1) to estimate wind speeds at these various heights rather than logarithmic method which is less conservative. These estimated velocities were then used to quantify approximately how much more power could be harnessed at higher rotor heights on the Xscape site. This was fed into a cost - benefit model for analysis on the technical and economical implications for increasing the tower height.

Power Law:

$$\frac{V}{V_o} = \left(\frac{H}{H_O}\right)^{\alpha} \tag{4.4.1}$$

Where:

V = Wind speed (m/s) at new hub height (extrapolated height)

V_o = Wind speed (m/s) at reference height (measured height)

H = New hub height (m)

H_o = Reference height (m)

α = Power law coefficient

The power law coefficient has been derived for a number of locations and approximately around the following values shown below for the corresponding locations [2].

$\alpha = 1/7$ for open country and coastal areas

$\alpha = 1/4.5$ for wooded areas, towns and rough coastal areas

$\alpha = 1/3$ for centres of large cities

Popular amongst these values is 1/7 which is used for commercial wind farm development project appraisals and is commonly referred to as the 1/7th law. However, because of the location of the Xscape site (Braehead) which is in a large city (Glasgow, Scotland), one – third was chosen as a fair representation for the power law coefficient for the site. Table 3 below is a summary of the monthly average mean wind speeds at the various extrapolated heights.

Table 3: Monthly Average Mean Wind Speed (m/s)

Month	Reference Height (6m)	Extrapolated Heights		
		15m	30m	80m
March	5.3	7.2	9.1	12.2

April	5.9	7.5	9.8	13.5
May	4.0	5.5	6.9	9.6
June	3.1	4.2	5.0	7.0
Average speed (m/s)	4.6	6.1	7.7	10.6

4.4 References:

[1] Manwell, J. F., et al, Wind Energy Explained, John Wiley and Sons Publication, England, 2002, p72.

[2] Davenport, A.G., A Rational for the Determination of Design Wind Velocities, proc. Paper 2476, Journal of Structures, Div ASCE, Vol. 86, no. ST5, May 1960, p39 – 68.

Chapter 5

Demand - Supply Matching

5.0 Introduction

Wind power as a renewable energy alternative is by far the most successful technology in the UK and many other places in the world. Wind turbines these days are readily available in different sizes from a few watts to 100 kW in the small turbine category and extend to about 2 MW for larger commercial farm types. Specifically there are currently over 146 small wind turbine models (Forsyth, T., et al, 1997) to choose from. Most of these are horizontal axis turbines rather than vertical axis types. Ducted wind turbine concept is also in its research and development stages

.

For this study, seven horizontal axis turbines and one vertical axis turbine were considered for the options appraisal.

5.1 Turbine Options Appraisal

In selecting a turbine to the supply the requisite power for the Xscape site, available small turbines were classified into groups based on their power ratings. All have capacities suitable for meeting the electricity demands on the Xscape site.

One turbine was then short listed from each group based on the overall potential power and energy yield determined using the swept area intercepting the wind, robustness which was determined by the specific mass (weight to area ratio), cost and maintenance requirements specified by the manufacturers. The turbines considered for this process were:

Horizontal axis turbines (HAWT)

- Renewable Device's Swift (1.5 kW turbine)
- Bergey Windpower 1500-24 (1.5 kW turbine)
- Proven WT 6000 (6 kW turbine)
- Proven WT 15000 (15 kW turbine)
- Wind Turbine Industry's WTI 26 -15 (15 kW turbine)
- Wind Turbine Industry's WTI 29 -20 (20 kW turbine)
- Westwind (20 kW turbine)

Vertical axis turbine (VAWT)

- Ropatec WRE.060 (6 kW turbine)

Turbine groupings:

The turbines considered above were then put into one of four groups as shown below.

Table 4: Group 1: 1.5 kW Rated Turbines

Turbine	Swept Area (m^2)	Rated Speed (m/s)	Specific Mass (kg/m^2)	Unit Cost (£)	Maintenance
Swift	3.14	10.5		£1,500	Low
Bergey BWC 1500	7.07	11.6	10.75	£2,500	

Table 5: Group 2: 6 kW Rated Turbines

Turbine	Swept Area (m^2)	Rated Speed (m/s)	Specific Mass (kg/m^2)	Unit Cost (£)	Maintenance
Proven WT 6000	23.8	10	16.8	£7,765	Low
Ropatec WRE.060	14.52	14	34.4	£9,500	Low

Table 6: Group 3: 15 kW Rated Turbines

Turbine	Swept Area (m^2)	Rated Speed (m/s)	Specific Mass (kg/m^2)	Unit Cost (£)	Maintenance
Proven WT 15000	63.62	14.0	17.3	£14,900	Low
WTI 26 – 15	49.32	11.6	17.5	£12,700	Moderate

Table 7: Group 4: 20 kW Rated Turbines

Turbine	Swept Area (m^2)	Rated Speed (m/s)	Specific Mass (kg/m^2)	Unit Cost (£)	Maintenance
WTI 29 – 20	61.40	11.6	17.0	£13,000	Moderate
Westwind 20	84.95	14.0	8.8	£20,600	Moderate

5.1.1 Selected Turbine

Group 1:

The Swift turbine was chosen from this group based on the numerous successes it has achieved since its introduction which includes the prestigious Ashden Sustainable Energy Award in 2005 for Energy Generation (Electricity Category) [9]. The Bergey though successful has seen a new model XL1 (1 kW rated) being promoted as a replacement by its manufacturer. The Swift is rooftop mounted and has a UK manufacturer hence lower shipment cost, thus made the scales tilt in its favour.

Table 8: Group 1 Results Summary

Turbine	Highest power output	Most Robust	Lowest Cost	Lowest Maintenance Requirements
Swift			√	√
Bergey 1500-24	√	√		

Group 2:

For group 2, 6 kW rating category, two turbines (Proven WT 6000 and Ropatec WRE.060) were chosen. The Proven WT 6000 had the potential to generate more power for the same wind speed and air density, as it had a bigger swept area. However the Ropatec turbine has a higher specific mass (twice that of the Proven WT 6000) and hence all being equal should be more robust and therefore would be better in severe weather conditions. However the lower cost of the Proven turbine must be considered.

Table 9: Group 2 Results summary:

Turbine	Highest power output	Most Robust	Lowest Cost	Lowest Maintenance Requirements
Proven WT 6000	√		√	√
Ropatec WRE.060		√		√

Group 3:

Proven WT 15000 was selected in this 15 kW rating category as it has a bigger swept area, less expensive, and turns out to be equally as robust and requires low maintenance as the WTI 26-15.

Table 10: Group 3 Results Summary:

Turbine	Highest power output	Most Robust	Lowest Cost	Lowest Maintenance Requirements
Proven WT 15000	√		√	√
WTI 26-15		√		√

Group 4:

Of the two turbines to choose from in this category (20 kW rating), the Westwind 20, has the potential of producing more power, has lower cost per turbine unit and requires low maintenance. Its lower robustness does not stop it from coming up tops against Wind Turbine Industry’s 29-20.

Table 11: Group 4 Results Summary:

Turbine	Highest power output	Most Robust	Lowest Cost	Lowest Maintenance Requirements
Westwind 20	√		√	√
WTI 26-15		√		√

5.1.2 Turbine Details

The details of the selected turbines from the four groups in section 5.1.1 and an overview of their manufacturers with examples of instances they have been used are discuss in the section below.

Swift

The Swift rooftop mounted wind turbines are upwind horizontal axis wind turbines manufactured by Renewable Devices based in Edinburgh, Scotland. The turbines can be utilised for grid – connected embedded power generation, installed with a battery bank for off-grid stand – alone applications or linked to an immersion water heating system.

Figure 5.1: A mounted Swift turbine

(Source: Renewable Devices)

The Swift turbines are mounted on a bespoke aluminium mast with a minimum blade roof clearance of approximately 0.5 meters. The turbines have been designed to avoid them transmitting oscillations and vibrations to the buildings they are mounted on through a damping system incorporated in its mounting brackets. It also comes with a patented ring diffuser that minimises turbine noise and the prevention of turbulent vortices at the blade tip [1]. In extreme weather conditions, the turbine has a twin – vane progressive mechanical furling mechanism to control its operation and to ensure it is not damaged.

Swift rooftop turbines have been installed at the BP filling station, Ingliston, Edinburgh (see figure 5.2) and at Colleydean primary school, Glenrothes, Fife. Table 12 below presents a summary of the turbine specification of Renewable Devices' Swift 1.5 kW turbine specifications used in this study.

Table 12: Swift 1.5 kW Turbine Specifications

Swift 1.5 kW	
Rotor Diameter (m)	2
Rated Wind Speed (m/s)	10.5
Rated Output (kW)	1.5
Annual Output (kWh)	4500
Number of blades	5

Figure 5.2: Swift at Ingliston BP station

Westwind Turbines

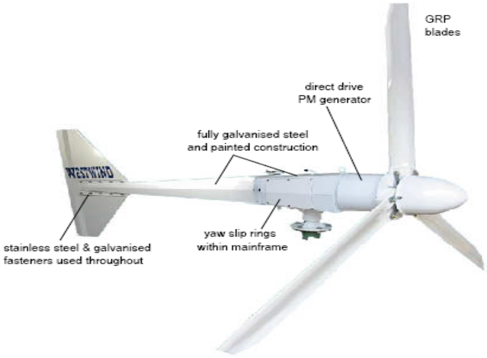

Figure 5.3: A Westwind turbine

Westwind is one of the major internationally renowned manufacturers of small scale wind turbines with models varying in sizes from 3 kW to 20 kW. The company's head office is based in Perth, Western Australia.

All Westwind turbines are three bladed, up-wind horizontal axis turbines and enjoy the reputation in the small wind turbine market as one of the most heavy duty and robust turbines available. The turbine rotor is directly attached to a permanent magnet generator. These turbines employ auto-furling control techniques to turn the blades out of strong winds. The 20 kW model is the latest addition to the addition to the Westwind turbine family.

According to Westwind company profile, over 210 Westwind wind turbines are in service around the world, with a combined capacity of 15000 kW [2]. Westwind turbines are mainly exported to overseas markets including the UK, Japan, Germany, China, India and Croatia. Table 13 below presents a summary of Westwind's 20 kW turbine specifications used in this study.

Table 13: Westwind 20 kW turbine specifications

Westwind 20 kW	
Rotor Diameter (m)	10.4
Cut in Wind Speed (m/s)	3.0
Rated Wind Speed (m/s)	14
Head Weight (kg)	750
Rated Output (kW)	20
Number of blades	3

Figure 5.4: 20 kW Westwind turbines at Exmouth, Australia

Proven Energy

Proven Energy is a UK based family owned business located in Stewarton in South West Scotland. It is into the manufacture of wind turbines, solar photovoltaic panels and hydro energy systems.

It manufactures a range of small wind turbines up to 15 kW. These proven turbines have the ability to produce power even in extreme weather conditions including hurricanes. Its recently developed 15 kW turbine (WT 15000) is ideal for light industrial, light commercial and agricultural use and presently the most highly sort after of all its models.

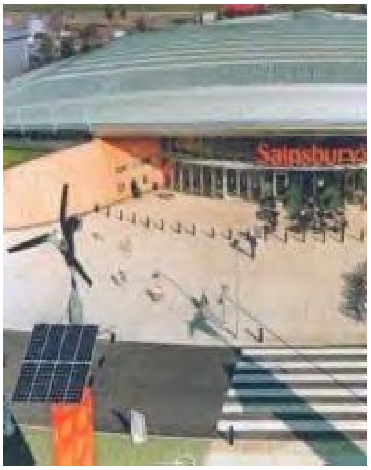
Figure 5.5: *Proven turbine at Sainsbury's supermarket in Greenwich, London.*

The company has so far installed 700 wind turbine systems in over 30 countries around the globe with its client portfolio spanning several major industries. Among them are multinational oil companies (BP, Shell and Saudi Aramco), Telecommunication giants (O2, T – mobile and Orange), Hardware and DIY suppliers (B&Q), Supermarkets (Sainsbury's) and Environmental organisations (Greenpeace). Table 14 & 15 below present a summary of Proven's 6 kW and 15 kW turbine specifications respectively used in this study.

Table 14: Proven WT 6000 Turbine Specifications

Proven Energy WT 6000	
Rotor Diameter (m)	5.5
Cut in Wind Speed (m/s)	2.5
Rated Wind Speed (m/s)	12
Cut – Out Wind Speed (m/s)	None
Survival Wind Speed (m/s)	65
Rotor Weight (kg)	500
Rated Output (kW)	6
Annual Output (kWh) in an average 5m/s wind speed	11,622
Number of blades	3

Figure 5.6: Proven turbine at a BP filling station (Source: www.provenenergy.co.uk)

Table 15: Proven WT 15000 Turbine Specifications

Proven Energy WT 15000	
Rotor Diameter (m)	9
Cut in Wind Speed (m/s)	2.5
Rated Wind Speed (m/s)	12
Cut – out Wind Speed (m/s)	None
Survival Wind Speed (m/s)	65
Rotor Weight (kg)	1100
Rated Output (kW)	15
Annual Output (kWh) in an average 5m/s wind speed	29,000
Number of blades	3

Ropatec AG

Figure 5.7: A Ropatec turbine in use in North America

Ropatec AG wind turbine manufacturing company is one of the only few small vertical axis wind turbine manufacturing companies around. Established in 1996, it has been manufacturing turbines in large quantities since 2001 from its business innovation centre in Bolzano, Italy. The company specialised in vertical axis turbines from the range of 0.75 kW to 6 kW. They are specially designed and manufactured to be robust so as to withstand extreme wind velocities. Ropatec turbine wind rotors are aerodynamically self regulating and therefore maintain a constant rotational speed even in extreme wind velocities. These Ropatec turbines use a gear – free, permanent producing, low-rev generator located in the central tube of the wind rotor as an external rotor type construction and are directly driven. This turbine generator is designed and manufactured by the company itself and has estimated efficiency of 85% to 90%.

Ropatec's vertical axis turbines have been used for many applications all over the world which include the following [4]:

- Muller Refuge: 50% of the total energy requirements at the Muller refuge centre in Italy are provided by Ropatec wind turbines since the summer of 1997.
- The lighthouse in Ireland has been using Ropatec wind turbines for its battery charging operations since August 2003.
- Water heating systems in the valley of Aosta in Italy are powered by two 6 kW Ropatec turbines since June 2002.

Table 16 below presents the summary of Ropatec's 6 kW vertical axis turbine used in this study.

Table 16: Ropatec WRE .060 Turbine Specifications

Ropatec WRE .060	
Rotor Diameter (m)	3.3
Cut in wind speed (m/s)	2
Rated wind speed (m/s)	14
Overspeed control	Not required
Rotor Weight (kg)	750
Rated Output (kW)	6
Annual Energy Output (kWh) (Average wind speed 5m/s)	3051

Figure 5.8 Ropatec WRE.060 Turbine

5.2 Power and Energy Estimations

As discussed in chapter four, wind velocity increases with height and that contributes increase in power harnessed. The results for power that can be extracted by the selected turbine models in section 5.1.1 using equation 2.1.1 for a speed range between 0 and 20m/s assuming air density at standard conditions are presented in the graph shown in figure 5.9 below.

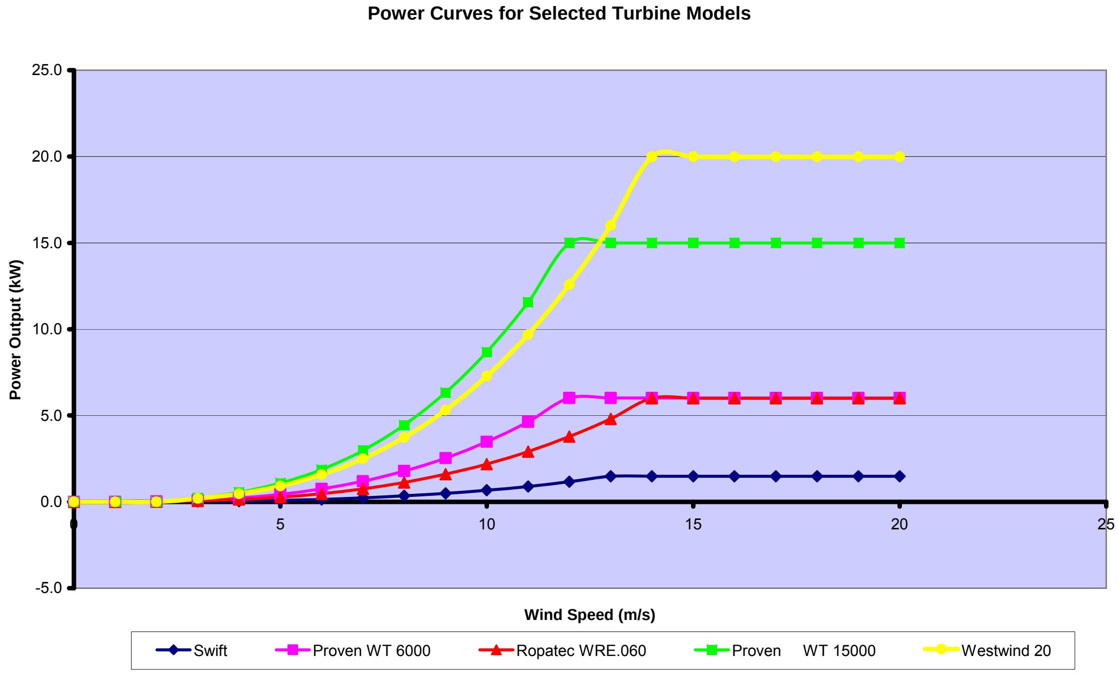

Figure 5.9: Power curves for selected turbine models

The number of hours for which the wind blows at a given speed is then multiplied by the instantaneous power output at that speed to obtain the energy captured at that speed. Table 17 below shows the actual energy captured for the month of April using measured wind speed data on the Xscape site. The details of the energy captured for the other three months are shown in Appendix C.

Table 17: Power and Energy Outputs for Selected Turbines at 15m Hub Height for April

		Swift		**Proven WT 6000**		**Ropatec WRE.060**		**Proven WT 15000**		**Westwind 20**	
Wind Speed (m/s)	Total Number of Hours in Bin	Power Output (kW)	Energy Captured (kWh)	Power Output (kW)	Energy Captured (kWh)	Power Output (kW)	Energy Captured (kWh)	Power Output (kW)	Energy Captured (kWh)	Power Output (kW)	Energy Captured (kWh)
0	26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	52	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
1.5	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	20	0.0	0.1	0.0	0.0	0.0	0.4	0.1	1.4	0.0	0.0
2.5	0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0
3	43	0.0	0.8	0.1	4.0	0.1	2.5	0.2	10.1	0.2	8.5
3.5	0	0.0	0.0	0.1	0.0	0.1	0.0	0.4	0.0	0.3	0.0
4	30	0.0	1.3	0.2	6.7	0.1	4.2	0.6	16.7	0.5	14.0
4.5	0	0.1	0.0	0.3	0.0	0.2	0.0	0.8	0.0	0.7	0.0
5	72	0.1	6.1	0.4	31.3	0.3	19.7	1.1	78.1	0.9	65.6
5.5	0	0.1	0.0	0.6	0.0	0.4	0.0	1.4	0.0	1.2	0.0
6	45	0.1	6.5	0.8	33.8	0.5	21.3	1.9	84.4	1.6	70.8
6.5	0	0.2	0.0	1.0	0.0	0.6	0.0	2.4	0.0	2.0	0.0
7	36	0.2	8.3	1.2	42.9	0.8	27.0	3.0	107.2	2.5	89.9
7.5	24	0.3	6.8	1.5	35.2	0.9	22.2	3.7	87.9	3.1	73.8
8	28	0.3	9.7	1.8	49.9	1.1	31.4	4.4	124.5	3.7	104.4
8.5	0	0.4	0.0	2.1	0.0	1.3	0.0	5.3	0.0	4.5	0.0
9	28	0.5	13.7	2.5	71.0	1.6	44.7	6.3	177.2	5.3	148.7
9.5	35	0.6	20.2	3.0	104.4	1.9	65.7	7.4	260.5	6.2	218.6
10	32	0.7	21.6	3.5	111.3	2.2	70.0	8.7	277.8	7.3	233.1
10.5	0	0.8	0.0	4.0	0.0	2.5	0.0	10.0	0.0	8.4	0.0

11	32	0.9	28.7	4.6	148.1	2.9	93.2	11.6	369.8	9.7	310.3
11.5	26	1.0	26.6	5.3	137.5	3.3	86.5	13.2	343.3	11.1	288.0
12	38	1.2	44.2	6.0	228.4	3.8	143.7	15.0	570.1	12.6	478.3
12.5	0	1.3	0.0	6.0	0.0	4.3	0.0	15.0	0.0	14.2	0.0
13	21	1.5	31.1	6.0	126.2	4.8	100.9	15.0	315.0	16.0	336.1
13.5	0	1.5	0.0	6.0	0.0	5.4	0.0	15.0	0.0	17.9	0.0
14	31	1.5	45.9	6.0	186.3	6.0	186.1	15.0	465.1	20.0	619.6
14.5	0	1.5	0.0	6.0	0.0	6.0	0.0	15.0	0.0	20.0	0.0
15	21	1.5	31.1	6.0	126.2	6.0	126.1	15.0	315.0	20.0	419.8
15.5	0	1.5	0.0	6.0	0.0	6.0	0.0	15.0	0.0	20.0	0.0
16	28	1.5	41.4	6.0	168.3	6.0	168.1	15.0	420.0	20.0	559.7
16.5	0	1.5	0.0	6.0	0.0	6.0	0.0	15.0	0.0	20.0	0.0
17	4	1.5	5.9	6.0	24.0	6.0	24.0	15.0	60.0	20.0	80.0
17.5	0	1.5	0.0	6.0	0.0	6.0	0.0	15.0	0.0	20.0	0.0
18	12	1.5	17.8	6.0	72.1	6.0	72.0	15.0	180.0	20.0	239.9
18.5	0	1.5	0.0	6.0	0.0	6.0	0.0	15.0	0.0	20.0	0.0
19	3	1.5	4.4	6.0	18.0	6.0	18.0	15.0	45.0	20.0	60.0
19.5	0	1.5	0.0	6.0	0.0	6.0	0.0	15.0	0.0	20.0	0.0
20	1	1.5	1.5	6.0	6.0	6.0	6.0	15.0	15.0	20.0	20.0
20.5	0	1.5	0.0	6.0	0.0	6.0	0.0	15.0	0.0	20.0	0.0
21	1	1.5	1.5	6.0	6.0	6.0	6.0	15.0	15.0	20.0	20.0
Total Energy Captured (kWh)			**375.2**		**1737.7**		**1339.6**		**4339.1**		**4458.8**

Based on the results in table 17, the total number of turbines required to meet the monthly electricity demand for April on-site could then be estimated by dividing the electricity demand by the electricity generated per turbine. The results obtained are presented in table 18 below.

Table 18: Number of turbines required to meet demand at 15m height.

Turbine model	Total electricity demand (kWh)/month	Electricity generated per turbine (kWh)/month	Number of turbines
Swift	24898.14	375.18	66
Proven WT 6000	24898.14	1952.7	13
Ropatec WRE.060	24898.14	1339.64	19
Proven WT 15000	24898.14	4339.1	6
Westwind 20	24898.14	4458.82	6

This estimation was done similarly for turbines mounted at 30m and 80m hub height and yielded the results presented in Table 19.

Table19: Number of turbines required to meet demand at 30m and 80m height.

Turbine model	Total electricity demand (kWh/month)	Electricity generated per turbine (kWh/month)		Number of turbines	
		30m	80m	30m	80m
Swift	24898.14	515.1	670.41	48	37
Proven WT 6000	24898.14	2792.3	4110.6	9	6
Ropatec WRE.060	24898.14	1934.2	3104.1	13	10
Proven WT 15000	24898.14	5626.2	7147.1	5	4
Westwind 20	24898.14	6438.4	8607.7	4	3

5.3 Crane Mounting as a Siting Alternative

Turbine towers are essential requirements if one wants to harness a large proportion of the power available in the wind. However the economic implications for every meter increment (about £467 per meter for a 15 kW Proven turbine tower) in tower height puts limitations on the heights prospective buyers are willing to go. The desire to offset this huge cost has led to the development of rooftop mounted wind turbines by manufacturers such as Renewable Devices and resulted in extensive research and feasibility studies into building integrated wind energy systems.

Although many including Paul Gipe [5], a world renowned small and micro wind energy systems expert, do not recommend rooftop mounting, recent successes achieved by the Swift turbine designed by Renewable Devices is compelling a rethink of earlier objections.

It is in line with this new enthusiasm that this section of the study discusses crane mounting as mounting alternative for construction sites. It focuses on the capabilities of cranes (tower cranes) and then discusses the technical issues that have to be addressed in order to utilise cranes as a mounting alternative.

5.3.1 Overview of Cranes

Cranes are primarily designed to lift and lower loads. But in addition, they must also support loads induced by their operating environment, including the effects of wind, snow, ice, earthquakes, and temperature extremes.

There are different types of cranes used on construction sites with types varying based on configuration and capabilities. The crane types available on the market include:

- Overhead – mounted cranes
- Monopile and underhung cranes
- Straddle cranes
- Tower cranes

Crane mounting discussed in this section has however been narrowed down to tower cranes as they are by far the most common type of crane in Europe [6]. Construction crews on the Xscape site use tower cranes to lift steel, concrete, large tools like acetylene torches and generators, and a wide variety of other building materials.

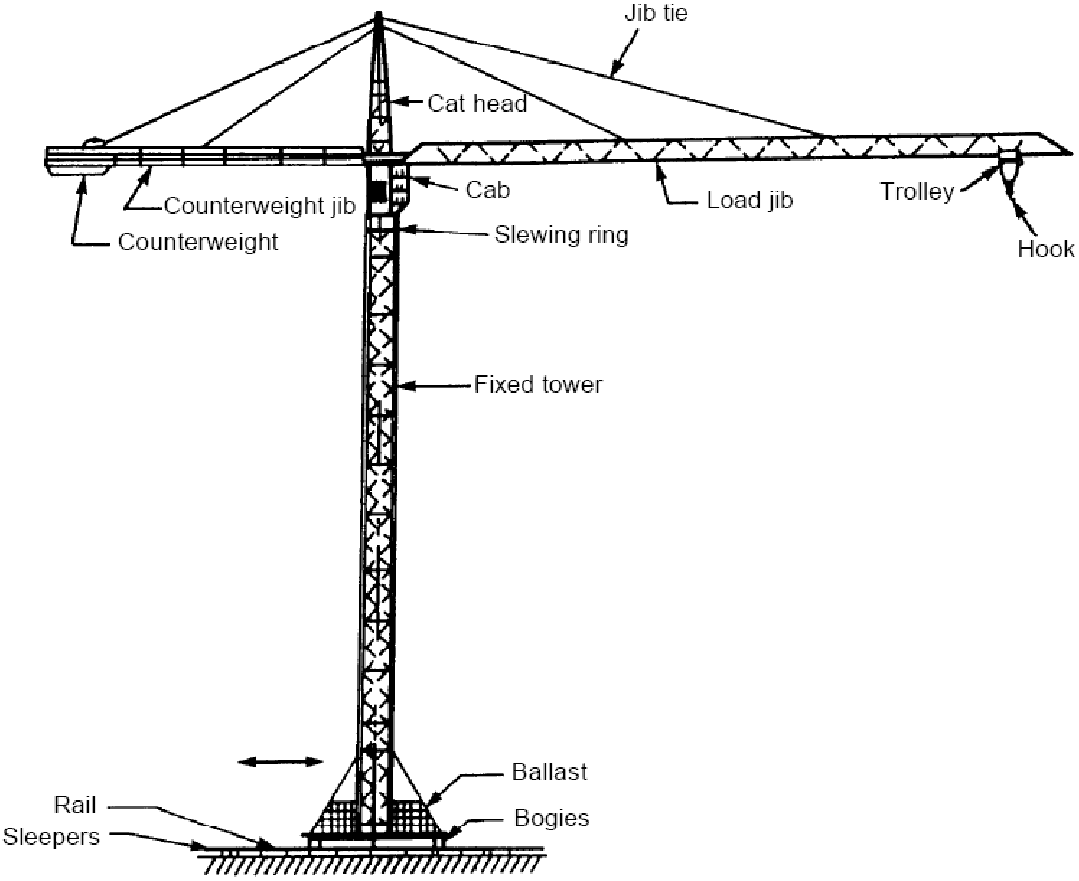

Figure 5.10: Tower Crane Schematic (source: Material handing handbook)

Tower cranes vary in size but a typical tower crane has the following specifications [7]:

- Maximum unsupported height - 80 meters

  the crane can have a total height much greater than 80 meters if it is tied into the building as the building rises around the crane.
- Maximum reach - 70 meters
- Maximum lifting power - 18 metric tons
- Counterweights - 16.3 metric tons

Although the maximum lifting power of the crane is 18,000 kg, it can only do so if the load is placed at the end of the jib. The maximum limiting moment thus becomes considerably important.

Stability of Cranes

The stability of cranes is of primary concern in their utilization. Because loads contribute immensely towards the destabilisation of cranes, cranes are designed to withstand four categories of loads namely [8]:

1. Vertical dead and live loads (including the weight of all attachments)
2. Horizontal wind loads on the tower and attachments (iced and uniced)
3. Unbalanced loads due to unbalanced attachments or variable tensions in attached conductors
4. Emergency loads, such as those of broken conductors, earthquakes, etc.

In order to for the cranes to be able to cope with these loads, three primary stability conditions must be met:

- Basic stability: Cranes under static loading in calm air with the rated load not to exceed two – thirds of the tipping load
- Dynamic stability: Crane in service with wind and other dynamic loads as appropriate and with rated loads taken as not more than 77% of the tipping load

- Stability under extreme loading: Crane out of service and subjected to storm, wind or earthquake effects.

The weight of turbines mounted on cranes would contribute to the live loads on the cranes. The fewer turbines mounted, the better it would be for the stability of the crane.

Wind and Wind loads

Wind effects on various structures and components such as cranes depend not only on the magnitude of the wind speeds, but also on the associated wind directions as well. For this reason, the knowledge of continuous joint probability distribution of extreme wind speeds and directions is always useful for a wind development project like this one.

Wind speeds vary randomly with time. This variation is due to the turbulence of the wind flow. The zone of lower turbulence is generally twice the height of the nearest obstacle such a tree or building as illustrated in figure 5.11 below.

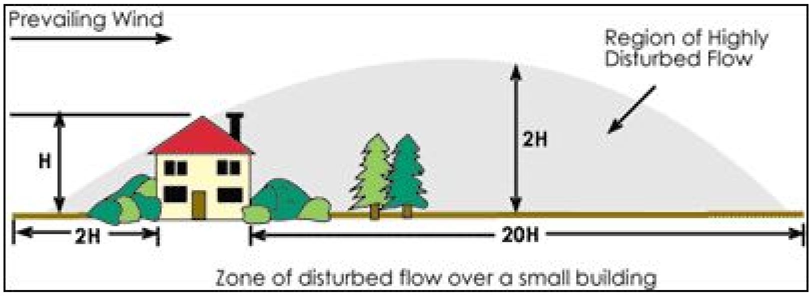

Figure 5.11: Wind distribution and turbulence zones

Tower mast elastic deflections (see illustration in figure 5.12) are caused by load eccentricity and by wind and are amplified by beam – column action, also called the P – Δ effect.

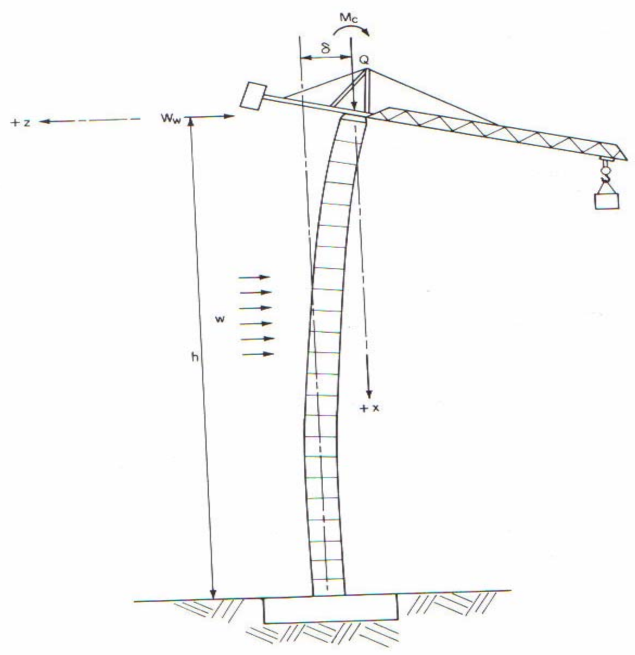

Figure 5.12: Tower elastic deflection under loads (source: Shapiro, H., Cranes & Derricks)

Crane mounted turbines would contribute to the elastic deflection the crane. There would therefore be the need to compute the additional deflection and verify if it is within acceptable limits. Below are formulae for computing the deflection and moments (with or without wind) for cranes given in handbooks on structures and cranes [6].

Crane Deflection and Moment Equations

If Mc (see figure 5.12) is the net moment about the crane centreline in the absence of wind, the displacement of the mast top from the centreline δc is given by:

$$\delta_c = \frac{M_c}{Q} \frac{1 - \cos kh}{\cos kh} \qquad (5.3.1)$$

Where:

Q = weight of the slewing portion of the crane (at the mast top) plus the load and one third of the mast weight

$$k = \left(\frac{Q}{EI} \right)^{1/2} \qquad (5.3.2)$$

Where:

E = Modulus of elasticity of the mast material

I = Moment of inertia of the mast cross section

With wind introduced, taking W_f as the wind force on the concentration of the exposure area above the slewing circle and w as the wind force per unit of length on the mast, we get

$$\delta_w = \frac{1}{Qk} \left[W_f (\tan kh - kh) + wh \left(\tan kh - \frac{kh}{2} \right) - \frac{w}{k} \frac{1 - \cos kh}{\cos kh} \right] \qquad (5.3.3)$$

Taking moment about the crane base gives

$$M_c' = M_c + Q\delta_c = \frac{M_c}{\cos kh} \qquad (5.3.4)$$

And for the wind moment M_w (noting that $M_w = M_wh + wh2/2$)

$$M'_w = M_w + Q\delta_w = (W_w + wh)\frac{\tan kh}{k} - \frac{w}{k^2}\frac{1-\cos kh}{\cos kh} \qquad (5.3.5)$$

In addition to reducing deflection and balancing moments of turbine loads on the crane, the Baumister equation given in equation 2.3.2 should be used to ensure there are no resonance excitations which could result in damaging the turbine or portions of the tower crane structure leading to serious health and safety implications.

5.4 References:

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http://www.provenenergy.co.uk/images/stories/PDFs/specifications.pdf

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[6] Shapiro, H. I., et al, Cranes and Derricks, McGraw Hill, USA, 1980, p77, p163

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Chapter 6

Economic Appraisal

6.0 Introduction

Previous chapters in this report have proven that technically small wind turbines can be utilised to produce energy to meet the demands on the Xscape site. However, in order for it to be a viable alternative to the supply technology (diesel power) in place, they must be cost effective. The economic viability of a small wind power system depends to a large extent on the generating costs and the associated market value of wind energy [1].

Capital cost, financial cost, operating and maintenance costs, turbine availability, energy efficiency, life time of turbine and site wind regime constitute the total generating costs. On the other hand, monetized environmental benefits which comprise emissions reduction (CO_2 savings) and reduced fossil fuel use, together with fuel savings and capital savings make up the associated market value of wind energy.

A number of wind energy researchers and turbine manufacturers have developed software and other spreadsheet models [2, 3, 4] to assist developers considering wind in their assessment and overall economic appraisal of wind power projects.

This chapter focuses on quantifying the overall costs for the utilization of small wind turbines as a supply alternative on the Xscape site.

6.1 Generating Costs Assessment

1. Availability

The availability is the fraction of the time of the year that the wind turbine is able to generate electricity. The unavailability times include shut down time for periodic maintenance as well as unscheduled repairs. Availability figures are obtained from data on similar turbines in operation for many years. World energy council quotes availability of wind turbines in the 80's to be 95%. In recent times however, the figures have shot up to 98% [1].

2. Lifetime of the System

Definition of lifetime of the wind turbine system varies, but usually manufacturers' estimated design lifetime of turbines has been used in economic assessment as the lifetimes of the systems. In Europe however, the Danish Wind Turbine Association's (1998) suggestion of a 20 year design lifetime as a useful economic compromise has now been adopted by many as a guide for developers of components for wind turbines [4]. American developers tend to use a 30 year design lifetime.

3. Capital Costs

These are the costs expected (or total investment) before the beginning of operations. They include the cost of the wind turbine (s), and the cost of the remaining installations. Generally, wind turbine installed costs are normalized to cost per unit of rotor area or cost per rated kW.

4. Financing Costs

Wind power projects are capital intensive but in most cases do pay for themselves in a short to medium time frame. Usually developers, make a down payment and finance the rest of the project with a loan obtained from a financial institution, in most cases a bank. The return on the money borrowed from the financial institution is called the interest.

5. Operation and Maintenance Costs

From time to time, regular maintenance operations have to be carried out to ensure the wind turbine systems are in good working condition and operating at the required level. In the early years the costs are between 1.5% and 3% of the turbine cost but increase with time as the turbines get older.

6.2 Cost Calculator for Small Scale Wind Utilisation on the Xscape Site

The details of economic appraisal for the Xscape site using a small turbine to meet the lighting demands alone are represent in the section below.

Case 1: Lighting Demand – Supply Economics

Demand and Supply Summary

In the using the selected turbine, Proven WT 15000, a brief summary of the Demand and supply is provided in table 20 below.

Table 20: Demand and Supply Summary

Total annual lighting demand (kWh/year)	20,042.88
Annual energy generation per turbine (kWh/year) at 30m	36,562.8
Number of turbines required	1
Total cost of wind turbines (£)	£14,900

Initial capital investment

This initial investment determines how much is borrowed from the bank. A higher initial investment would mean less money borrowed and lower paid interest on the money borrowed. However that would also lead to lower disposable cash on the part of the investor, in this case Laing O'Rourke. For this study a 20% capital investment in the turbines have been used and an overall 45% initial capital investment (down payment or equity invested) involving monies paid towards the cost of the turbine tower, controllers and engineering works for installation.

Initial capital investment in turbines = 20% of turbine cost

= 0.20*14,900

= £2,900

Total down payment for the entire system cost = 45% of total cost of turbines, controllers, towers and engineering works.

= 0.45 * (14,900 + 565 + 15,000 + 6,093)

= £16,401

Amount to be borrowed = Total cost of the entire system – Total down payment

= 36,558 – 16,401

= £20,107

Loan payment details

The details for the loan repayment can then be computed using the time value of money and present worth factor approach.

Interest rate on loan = 10%

Term of loan = 10 years

Annual repayment = $$\frac{PV * r}{\left[1-(1+r)^{-N}\right]} \qquad (6.2.1)$$

Where:

PV = present value of loan

r = Interest rate

N = Term of loan

Annual repayment = $$\frac{20{,}107 * 0.10}{\left(1-(1+0.10)^{-10}\right)}$$

= £3,272.32

Operation and Maintenance (O & M) Cost

A ‘block’ approach for operation and maintenance cost estimation has been used in this study. Year 1 makes up one block, year 2 – 5 another, year 6 – 10, year 11 – 15 and year 16 – 20 make up the remaining blocks.

For year 1 the operation and maintenance cost is estimated as 2% of the total turbine cost.

The O & M cost for each year in the Year 2 – 5 ‘block’ is given as 2% of the turbine cost + 1% of the O & M cost for the previous year.

Year 6 – 10 = 2% of the turbine cost + 2% of the O & M cost for the previous year.

Year 11 – 15 = 2% of the turbine cost + 3% of the O & M cost for the previous year.

Year 16 – 20 = 2% of the turbine cost + 4% of the O & M cost for the previous year.

Property Tax and Insurance Cost

A fixed estimate of 1.7% of the cost of the turbines, controllers and towers, amounting to £517.91 per annum was used for the 20 year design lifetime of the system.

Equipment Reserve, Lease and Others

To aid in maintenance, additional spare parts and others must be kept in store for rapid restoration of the power system back into operation in the event of a break down. The annual estimates have been computed in blocks like that done for the O & M costs.

Year 1 = 0.5% of the total cost of the turbines, tower and controllers

Year 2 – 5 = 0.5% of the total cost of the turbines + 0.5% of the equipment reserve cost for the previous year.

Year 6 – 10 = 0.5% of the total cost of the turbines + 0.7% of the equipment reserve cost for the previous year.

Year 11 – 15 = 0.5% of the total cost of the turbines + 1% of the equipment reserve cost for the previous year

Year 16 – 20 = 0.5% of the total cost of the turbines + 1.5% of the equipment reserve cost for the previous year.

The amounted to £3276.14 for the 20 year design lifetime of the system.

Total Expenditure

The annual expenses vary from £1,033.07 when the loan repayments have been completed to £4,293.51 when the loan is still being repaid with moderate maintenance and stock of parts.

However the total lifetime expenditure = Σ (Annual repayment + annual O & M expenses + annual property tax and insurance + annual equipment reserve and lease expenses).

= £32,723.20 + £7274.16 + £10,358.10 + £3276.14

= £53, 631.60

Table 21 below (an extract from the economic appraisal spreadsheet model), gives a detailed breakdown of annual expenditures.

Cost of Energy from Turbines

$$\text{Cost of energy per kWh} = \frac{TotalLifetimeCosts}{DesignLifeofSystem * AnnualEnergyOutput} \qquad (6.2.2)$$

$$\text{Cost of energy per kWh} = \frac{53{,}631.60}{20 * 36{,}562.8}$$

$$= 0.0733 \text{ £/kWh}$$

$$= 7.33\text{p/kWh}$$

Table 21: ECONOMIC EVALUATION OF WIND TURBINE INVESTMENT

	Principal and Interest Payments for borrowed funds					Wind Turbine kWh Generation		Annual Operating Expenses			
Year	Beginning Principal	Annual Payment	Interest	Ending Principal	Equity Invested (Cash from savings)	Annual kWh Generated	Amount that is used	Operation & Maintenance Expenses	Property Tax & Insurance	Equipment, Reserve, or lease	Annual Total Expenditure
1	£20,107	£3,272.32	£2,010.69	£18,845.27	£16,451	36,562.8	36,562.8	£298.00	£517.91	£152.33	**£4,240.55**
2	£18,845.27	£3,272.32	£1,884.53	£17,457.48	£0	36,562.8	36,562.8	£300.98	£517.91	£153.09	**£4,244.29**
3	£17,457.48	£3,272.32	£1,745.75	£15,930.90	£0	36,562.8	36,562.8	£303.99	£517.91	£153.85	**£4,248.07**
4	£15,930.90	£3,272.32	£1,593.09	£14,251.68	£0	36,562.8	36,562.8	£307.03	£517.91	£154.62	**£4,251.88**
5	£14,251.68	£3,272.32	£1,425.17	£12,404.52	£0	36,562.8	36,562.8	£310.10	£517.91	£155.39	**£4,255.72**
6	£12,404.52	£3,272.32	£1,240.45	£10,372.65	£0	36,562.8	36,562.8	£316.30	£517.91	£156.48	**£4,263.01**
7	£10,372.65	£3,272.32	£1,037.27	£8,137.60	£0	36,562.8	36,562.8	£322.63	£517.91	£157.58	**£4,270.43**
8	£8,138	£3,272.32	£813.76	£5,679.04	£0	36,562.8	36,562.8	£329.08	£517.91	£158.68	**£4,277.99**
9	£5,679	£3,272.32	£567.90	£2,974.62	£0	36,562.8	36,562.8	£335.66	£517.91	£159.79	**£4,285.68**
10	£2,975	£3,272.32	£297.46	£0.00	£0	36,562.8	36,562.8	£342.38	£517.91	£160.91	**£4,293.51**
11	£0	£0.00	£0	£0.00	£0	36,562.8	36,562.8	£352.65	£517.91	£162.52	**£1,033.07**
12	£0	£0.00	£0	£0.00	£0	36,562.8	36,562.8	£363.23	£517.91	£164.14	**£1,045.28**
13	£0	£0.00	£0	£0.00	£0	36,562.8	36,562.8	£374.12	£517.91	£165.79	**£1,057.81**
14	£0	£0.00	£0	£0.00	£0	36,562.8	36,562.8	£385.35	£517.91	£167.44	**£1,070.70**
15	£0	£0.00	£0	£0.00	£0	36,562.8	36,562.8	£396.91	£517.91	£169.12	**£1,083.93**
16	£0	£0.00	£0	£0.00	£0	36,562.8	36,562.8	£412.78	£517.91	£171.65	**£1,102.34**
17	£0	£0.00	£0	£0.00	£0	36,562.8	36,562.8	£429.29	£517.91	£174.23	**£1,121.43**
18	£0	£0.00	£0	£0.00	£0	36,562.8	36,562.8	£446.47	£517.91	£176.84	**£1,141.21**
19	£0	£0.00	£0	£0.00	£0	36,562.8	36,562.8	£464.33	£517.91	£179.50	**£1,161.73**
20	£0	£0.00	£0	£0.00	£0	36,562.8	36,562.8	£482.90	£517.91	£182.19	**£1,182.99**
Total	£20,107	£32,723.20	£12,616.07		£16,451			£7,274.16	£10,358.10	£3,276.14	**£53,631.61**

Case 2: Lighting and Heating Demand – Supply Economics

The appraisal was similarly done with the aim of meeting both lighting and heating during the heating season (winter) and yielded the results represented in table 22 and table 23 below.

Table 22: Lighting and Heating Demand - Supply Economics Summary

Total lighting and heating demand (kWh/year)	98,978.88
Annual Energy generation per turbine (kWh/year)	90,444
Number of turbines required	3
Total cost of wind turbines (£)	39,300
Initial capital investment in turbines (£)	7,860
Total Cost of entire system (£)	103,074
Total down payment (£)	46,383
Amount to be borrowed (£)	56,691
Loan Repayment (£)	9,226.15
Total Repayment (£)	92,261.5
Total O & M expenses (£)	19,186.22
Total property tax & insurance expenses (£)	29,204.30
Total equipment and reserve expenses (£)	9,236.97
Cost of Energy (p/kWh)	8.29

Table 23: ECONOMIC EVALUATION OF WIND TURBINE INVESTMENT

	Principal and Interest Payments for borrowed funds					Wind Turbine kWh Generation		Annual Operating Expenses			
Year	Beginning Principal	Annual Payment	Interest	Ending Principal	Equity Invested (Cash from savings)	Annual kWh Generated	Amount that is used	Operation & Maintenance Expenses	Property Tax & Insurance	Equipment, Reserve, or lease	Annual Total Expenditure
1	£56,691	£9,226.15	£5,669.07	£53,133.62	£46,383	90444	90444	£786.00	£1,460.22	£429.48	**£11,901.84**
2	£53,133.62	£9,226.15	£5,313.36	£49,220.83	£0	90444	90444	£793.86	£1,460.22	£431.62	**£11,911.85**
3	£49,220.83	£9,226.15	£4,922.08	£44,916.76	£0	90444	90444	£801.80	£1,460.22	£433.78	**£11,921.94**
4	£44,916.76	£9,226.15	£4,491.68	£40,182.29	£0	90444	90444	£809.82	£1,460.22	£435.95	**£11,932.13**
5	£40,182.29	£9,226.15	£4,018.23	£34,974.37	£0	90444	90444	£817.91	£1,460.22	£438.13	**£11,942.41**
6	£34,974.37	£9,226.15	£3,497.44	£29,245.66	£0	90444	90444	£834.27	£1,460.22	£441.20	**£11,961.83**
7	£29,245.66	£9,226.15	£2,924.57	£22,944.07	£0	90444	90444	£850.96	£1,460.22	£444.28	**£11,981.61**
8	£22,944	£9,226.15	£2,294.41	£16,012.33	£0	90444	90444	£867.98	£1,460.22	£447.39	**£12,001.74**
9	£16,012	£9,226.15	£1,601.23	£8,387.41	£0	90444	90444	£885.34	£1,460.22	£450.53	**£12,022.23**
10	£8,387	£9,226.15	£838.74	£0.00	£0	90444	90444	£903.04	£1,460.22	£453.68	**£12,043.09**
11	£0	£0.00	£0	£0.00	£0	90444	90444	£930.14	£1,460.22	£458.22	**£2,848.57**
12	£0	£0.00	£0	£0.00	£0	90444	90444	£958.04	£1,460.22	£462.80	**£2,881.05**
13	£0	£0.00	£0	£0.00	£0	90444	90444	£986.78	£1,460.22	£467.43	**£2,914.42**
14	£0	£0.00	£0	£0.00	£0	90444	90444	£1,016.38	£1,460.22	£472.10	**£2,948.70**
15	£0	£0.00	£0	£0.00	£0	90444	90444	£1,046.88	£1,460.22	£476.82	**£2,983.91**
16	£0	£0.00	£0	£0.00	£0	90444	90444	£1,088.75	£1,460.22	£483.97	**£3,032.94**
17	£0	£0.00	£0	£0.00	£0	90444	90444	£1,132.30	£1,460.22	£491.23	**£3,083.75**
18	£0	£0.00	£0	£0.00	£0	90444	90444	£1,177.59	£1,460.22	£498.60	**£3,136.41**
19	£0	£0.00	£0	£0.00	£0	90444	90444	£1,224.70	£1,460.22	£506.08	**£3,190.99**
20	£0	£0.00	£0	£0.00	£0	90444	90444	£1,273.68	£1,460.22	£513.67	**£3,247.57**
Total	£56,691	£92,261.50	£35,570.80		£46,383			£19,186.22	£29,204.30	£9,236.97	**£149,888.99**

6.3 References:

[1] Manwell, J. F., et al, Wind Energy Explained, John Wiley and Sons Publication, England, 2002, p427-431

[2] Retscreen, Wind Energy Project Model, http://www.retscreen.net/ang/pop_prod.php?idiableau=27&h=1

[3] Danish Wind Energy Association, Wind Energy Economics Calculator, http://www.windpower.org/en/tour/econ/econ.htm

[4] Windustry, Wind Project Calculator, http://www.windustry.com/calculator/wind%20Gen%20Analysis%20windustry%202003.xls

[5] Hunter, R., Elliot, G., Wind – Diesel Systems – A guide to the technology and its implementation, Cambridge University Press, 1994, p237 – 243.

Chapter 7

Results Discussion

7.0 Introduction

This chapter takes a closer look at the results obtained from the analysis carried out and presented in the previous chapters. It begins with a discussion of the wind resource data obtained, followed by the demand profile of the Xscape site, the supply profile and strategy and concludes with the implications of the economic appraisal results.

7.1 Wind Resource Data

As stated in Chapter 4, commercial wind power developers typically measure actual wind resource, in part, to determine the distribution of wind speeds for a full year. However because of the short time duration used for this study and the fact that historical data dating back to months before March 2005 are unavailable, only four months data collected could be used for the analysis and appraisal in this study.

This inevitably impacted on the results obtained, in that annual averages used for the estimation actually were more representative of a four month average rather than that of a twelve month period. The months themselves (March, April, May and June) were neither typical winter nor summer months in Glasgow hence the average wind speed obtained could have been altered significantly if additional data from typical winter and summer months were available.

Nevertheless, the average wind speed (4.6m/s) obtained at 6m for the site (representing 5.5m/s when extrapolated to a standard measurement height of 10m) was encouraging and indeed good for wind power generation.

Using the 30m extrapolation results for example, of the total 1837 hours in the bins from March to June, 81.6% of the time the wind speed is above 2m/s.

7.2 Demand Profile

As reported in earlier in the report, energy efficiency measures and recommendations are now being implemented on-site to keep demand in check. The worst case scenario (80% of all lights are on 12 hours a day and 50% of all heaters are on 12 hours of the day for 26 heating season weeks) used in this assessment, as against an actual energy audit of the site, would if anything over estimate the on-site demand.

However there was consistency in the analysis, in that the same scenario was used to assess the diesel generator supply option when compared with the wind turbine supply option.

7.3 Supply Option

Tower Height

The results from the wind resource assessment confirmed that the wind regime on the Xscape site is good enough to utilise wind turbines as a supply technology option. However, the average wind speed results and distribution at 15m are not the ideal as meeting demand with turbines mounted at this height would require more turbines and an unfavourable project and energy cost.

Although as expected, the wind speeds at 80m were higher, the wind forces at 80m are higher and require more and better structural support (foundation) to ensure the turbines and towers do not fall. Also the maximum standard tower height for the selected turbines is 30m, thus going above 30m would not satisfy design recommendations. The 80m estimation was primarily done for crane mounting. However there are technical limitations with crane mounting and an additional issue of planning permission, because planning permission is given for a crane as a lifting device and not for turbine mounting. Thirty meters (30m) should therefore be the recommended tower height.

Turbine Choice

The Proven WT 15000 turbine proved to be best supply option as it could generate nearly equal electricity as the 20 kW Westwind turbine because of the wind distribution. This is because the Proven turbine has a rated speed of 12m/s, and therefore when the wind blows for example 5.3% of the time at 12m/s at 30m, it would be generating more power that the Westwind turbine. At 12m/s, the Westwind turbine would be generating 65% of that of the Proven turbine. Only 20.9% of wind speed distribution is equal or greater than 14m/s to enable the Westwind turbine to generate power at its rated output whiles the Proven turbine would have 30.4% of the wind speed distribution to do so.

The Proven turbine is also £5700 cheaper than the Westwind turbine, has a UK, or better still, Scottish manufacturer meaning there would be easy access to parts and assistance with maintenance and repair in the event of an unexpected breakdown.

The other turbines with lower rated outputs (Swift, Ropatec WRE.060 and Proven WT 6000), would require more turbines to meet demand and that would be a problem when it comes to siting as more land space would be required to create an undisturbed wind regime for the other turbines to utilise. Hence the Proven WT 15000 was selected as the best turbine for the supply option.

In aiming to meet the lighting demands on site, one Proven WT 15000 (15 kW) turbine mounted at 30m could generate 36,500 kWh of electricity per annum and that would be enough to meet the total on-site annual lighting demand of 20,000 kWh with the excess of 16,500 kWh going towards other electricity demands such as heating.

7.4 Economics

The cost of energy per kWh of electricity generated using one Proven WT 15000 to meet lighting demands alone or both lighting and heating demands would be lower (7.33p/kWh and 8.29p/kWh respectively) than the price Laing O'Rourke would be paying as from next year (10.1p/kWh). This could even be cheaper considering that a worst case scenario (high interest rate, O&M and other expenses) was used for the appraisal. And therefore if the company could negotiate for a lower interest rate than the 10% used for the appraisal, and the turbines do not turn to have high operating and maintenance costs or need to keep that many parts in store, then the cost will be reduced further.

Thus although it is not and would not be cheaper than grid electricity, it is competitive and comparable with those from other stand alone distributed generation supply options.

7.5 Environmental Impacts

The environment impacts from the utilisation of small scale wind turbines on the Xscape site will be limited to noise pollution and visual impacts.

The noise levels from the Proven WT 15000 are 48dB (A) and 65dB (A) at wind speeds of 5m/s and 20m/s respectively [1]. These noise levels are generally classified as quiet and intrusive respectively (see table 24). With a 7.7m/s average on-site wind speed at 30m, noise levels from the turbines should be within acceptable limits.

Table 24: Sound Levels

Common Sounds	Noise Level (dB)	Effect/Classification
Library Soft Whisper	30	Very Quiet
Living Room Bedroom Quiet Office	40	
Light Auto Traffic	50	Quiet
Air Conditioning Unit Conversational Speech	60	Intrusive
Noisy Restaurant Freeway Traffic Business Office	70	Telephone Use Difficult
Alarm Clock Hair Dryer	80	Annoying
Rock Concert	110	Extremely Loud
Jet Take- Off (100m away)	120	Maximum Vocal Effort

(Source: Federico Miyara, Sound Levels)

Visual impacts will be as a result of the turbines obstructing and interfering with the skyline and landscape. However with the proposed project involving only one turbine mounted at 30m (which is lower than half the height of on-site tower crane) to meet lighting demands alone, it should not cause too much of a problem with visual intrusion.

The advantage of utilising the small scale wind turbine to supplement power supply is in the reduction of CO_2 emissions. The project could result in 59 tonnes of CO_2 savings per year. This was arrived at using the emission reduction calculation approach shown below.

Emission Reduction Calculation

The amount of CO_2 emissions from the proposed wind - diesel project for the Xscape site can be estimated from equation 7.5.1 below [3].

$$E = (\text{Cap} * \text{CEF}) * \text{LF} * \text{Hours} \qquad (7.5.1)$$

Where:

E = Emission amounts of the project activity

Cap = Diesel generator capacity (kW)

CEF = Carbon emission factor (kg CO_2/kWh)

LF = Load factor of the diesel plant

Hours = Number of hours in operation in year

$$\text{LF} = \frac{(\text{Diesel Electricity} - \text{Wind Electricity})}{\text{Cap} * \text{Hours}} \qquad (7.5.2)$$

Using the Proven 15 kW turbine to meet lighting demand alone, then:

Cap = 200 kW

Diesel Electricity Supply = 100,285.08 kWh/year

Wind Electricity Supply = 36,562.8 kWh/year

Hours = 3120 hours/year (12hours/day * 5days/week * 52weeks/year)

CEF = 0.93 kgCO_2/kWh (27% load)

$$LF = \frac{100{,}285.08 * 36{,}562.8}{200 * 3120}$$

$$= 0.102$$

E = 200 * 0.93 * 0.102* 3120 = 59,192.64 kgCO_2/year

7.6 References

[1] Proven Energy, Product Specifications,

http://www.provenenergy.co.uk/images/stories/PDFs/specifications.pdf

[2] Miyara, F., Sound Levels,

http://www.eie.fceia.unr.edu.ar/~acustica/comite/soundlev.htm

[3] Duc Minh, N., Introduction of PDDs of wind – diesel hybrid electricity and Dak Pone Hydropower projects, Seminar on Business Opportunities for Cogeneration projects.

http://www.cogen3.net/presentations/asean/cdm_hcm/PDDsoftwoCDMprojectsinVietnam.pdf

Chapter 8

Conclusions and Recommendations

8.0 Conclusions

The study highlighted the increasing need for the integration of renewable energy systems at the distributed generation level. Small scale wind turbines have found applications in numerous sectors including domestic, telecommunication and agricultural sectors. This diverse nature of their use can therefore be extended to the construction sector.

Wind speed data collected on-site, indicates that the wind regime on construction sites, and in this case the Xscape site, could be good for power generation using a small wind turbine. The study confirmed that wind speeds were higher at 80m and would favour crane mounting. However further technical analysis could not be undertaken as data on the tower cranes used on-site were not available.

The results from the turbine options appraisal indicate that a number of different small scale wind turbines can be utilised for power generation on-site. However, the cost-benefit analysis favoured the 15 kW Proven turbine (WT 15000).

The economic appraisal for the utilisation of the WT 15000 showed that it would be cheaper than the diesel supply option in place by 2.8p/kWh if the turbines are used to generate electricity to meet lighting demand only. One WT 15000 mounted at 30m can be utilised for this purpose with excess electricity generated going towards other demand needs.

If on-site demand is further reduced after the implementation of on-going energy efficiency measures, and estimated generating costs turn out to be lower, then the cost of energy would be even cheaper from the turbines and hence additional turbines can be used to meet the other electricity demands on-site.

The project when implemented would have very limited noise pollution and visual impacts which were identified as the likely impacts on the environment. It could also lead to an annual CO_2 emission savings of 59 tonnes.

8.1 Recommendations and Suggestions for Future Works

Additional wind speed data should be collected to make up a full year's data so that the average wind speed could be more reflective of the seasonal variations in wind speed.

Actual data on tower cranes on-site could be used to estimate the forces, deflections and resonance effects that would be in encountered if turbines are mounted on the cranes. The

Swift turbine, which transmits very little vibrations and designed for roof-top mounting should be considered first for such an application.

Appendix A

A.1: Detailed Site Energy Demand

Braehead Xscape Project Site
Temporary Accommodation Load Survey

Lighting Gear Losses	10%

Ground Floor

Room	Type of Electrical Appliance	Rating (W)	Number of appliances in simultaneous operation	Maximum wattage of appliances in simultaneous operation
Engineer				
	Lighting	36	4	158.4
	Heater	2000	2	4000
	Tower	350	1	350
	VDU	200	1	200
Drying Room				
	Heater	2000	2	4000
	Lighting	36	9	356.4
	Water Heaters	6000	1	6000
Toilet (Male)				
	Lighting	58	9	574.2
	Heating	150	3	450
Toilet (Female)				
	Lighting	58	6	382.8
	Heating	150	1	150
Canteen				
	Lighting	36	29	1148.4
	Heating	2000	4	8000
	Equipment (Total)	10000	1	10000
First Floor				
Office 1				
	Lighting	36	4	158.4
	Heating	2000	2	4000
Office 2				
	Lighting	36	4	158.4
	Heating	2000	2	4000
Office 3				
	Lighting	36	2	79.2
	Heating	2000	1	2000
Office 4				
	Lighting	36	2	79.2

	Heating	2000	1	2000
Office 5	Lighting	36	2	79.2
	Heating	2000	1	2000
Kitchen	Lighting	36	2	79.2
	Water Heater	3000	1	3000
Toilets (Male)	Lighting	36	2	79.2
	Heater	150	2	300
Toilets (Female)	Lighting	36	2	79.2
	Heater	150	2	300
Office 6	Lighting	36	2	79.2
	Heating	2000	1	2000
	Laptop	150	1	150
	TFT	34	2	68
	Tower	350	1	350
Office 7	Lighting	36	2	79.2
	Heating	2000	1	2000
	Laptop	150	1	150
	TFT	34	2	68
Office 8	Lighting	36	2	79.2
	Heating	2000	1	2000
	Laptop	150	1	150
Office 9	Lighting	36	4	158.4
	Heating	2000	2	4000
	Laptop	150	4	600
Office 10	Lighting	36	2	79.2
	Heating	2000	1	2000
	Laptop	150	2	300
Office 11	Lighting	36	2	79.2
	Heating	2000	1	2000
	Laptop	150	2	300
Office 12	Lighting	36	4	158.4
	Heating	2000	2	4000
Office 13	Lighting	36	4	158.4

	Heating	2000	2	4000
	VDU	300	1	300
	Tower	350	1	350
	Laptop	150	4	600
Office 14				
	Lighting	36	4	158.4
	Heating	2000	2	4000
	Laptop	150	3	450
	TFT	34	3	102
Office 15				
	Lighting	36	2	79.2
	Heating	2000	1	2000
	Laptop	150	2	300
	TFT	34	1	34
	Tower	350	1	350
Corridor				
	Lighting	36	10	396
Reception				
	Lighting	36	3	118.8
	Heating	2000	1	2000
JackLeg 1				
	Lighting	58	5	319
	Heating	2000	2	4000
JackLeg 2				
	Lighting	58	5	319
	Heating	2000	2	4000
JackLeg 3				
	Lighting	58	5	319
	Heating	2000	2	4000
JackLeg 4				
	Lighting	58	5	319
	Heating	2000	2	4000
JackLeg 5				
	Lighting	58	5	319
	Heating	2000	2	4000
JackLeg 6				
	Lighting	58	5	319
	Heating	2000	2	4000
JackLeg 7				
	Lighting	58	5	319
	Heating	2000	2	4000
JackLeg 8				
	Lighting	58	5	319
	Heating	2000	2	4000
JackLeg 9				
	Lighting	58	5	319
	Heating	2000	2	4000
Induction				

Cabin				
	Fluorescent tube lighting - single strip	58	2	127.6
	Heating	2000	2	4000
Total				**133,406**

Appendix B

B. 1 Wind Speed Distribution on – Site

	March			April			May			June		
	Number of hours in bin at height											
Wind Speed (m/s)	15m	30m	80m	15m	30m	80m	15m	30m	80m	15m	30m	80m
0	39	39	39	26	26	26	47	47	47	41	41	41
0.5	0	0	1	0	0	0	0	0	0	0	0	0
1	29	17	26	52	24	24	39	19	19	63	33	33
1.5	0	0	1	0	0	0	0	0	0	0	0	0
2	14	12	19	20	28	28	28	22	20	24	30	30
2.5	0	0	0	0	0	0	0	0	0	0	0	0
3	30	29	0	43	39	0	38	48	0	47	52	0
3.5	2	0	0	0	0	0	0	0	0	0	0	0
4	15	15	14	30	24	20	11	18	28	18	19	24
4.5	0	0	2	0	0	0	0	0	0	0	0	0
5	43	17	14	72	30	19	36	11	20	27	18	28
5.5	0	0	0	0	0	0	0	0	0	0	1	0
6	29	23	13	45	30	24	15	16	18	11	10	19
6.5	0	0	0	0	0	0	0	0	0	0	0	0
7	27	20	16	36	42	31	17	20	11	6	16	18
7.5	30	0	0	24	0	0	15	0	0	15	0	0
8	32	29	20	28	45	29	13	13	16	16	11	11
8.5	0	25	0	0	34	0	0	15	0	0	5	0
9	29	32	0	28	26	1	15	15	0	16	16	1
9.5	30	0	18	35	0	41	18	0	20	13	0	15
10	26	32	0	32	28	0	12	13	0	8	16	0
10.5	0	0	0	0	0	0	0	0	0	0	0	0
11	21	29	27	32	28	45	8	15	15	2	16	11
11.5	15	0	0	26	0	0	10	0	0	3	0	0
12	15	30	22	38	36	34	7	18	17	5	13	5
12.5	0	0	0	0	0	0	0	0	0	0	0	0
13	13	26	31	21	31	26	3	12	15	1	8	16
13.5	0	0	0	0	0	0	0	0	0	0	0	0
14	16	21	31	31	32	28	7	8	13	2	2	16
14.5	0	16	0	0	27	0	0	10	0	0	3	0
15	8	14	29	21	36	28	3	7	15	1	5	16
15.5	0	0	0	0	0	0	0	0	0	0	0	0
16	4	13	0	28	22	0	3	3	0	0	1	0
16.5	0	0	0	0	0	0	0	0	0	0	0	0
17	3	10	28	4	18	36	1	5	18	0	2	13
17.5	0	0	0	0	0	0	0	0	0	0	0	0

18	4	6	26	12	13	31	5	2	12	0	0	8
18.5	0	0	0	0	0	0	0	2	0	0	0	0
19	0	8	20	3	21	32	0	3	8	0	1	2
19.5	0	0	0	0	0	0	0	0	0	0	0	0
20	3	3	16	1	16	27	0	2	10	0	0	3
20.5	0	1	0	0	12	0	0	1	0	0	0	0
21	1	3	13	1	4	37	0	1	7	0	0	5
21.5	0	0	0	0	0	0	0	0	0	0	0	0
22	0	3	0	0	7	0	0	4	0	0	0	0
22.5	0	0	13	0	0	21	0	0	3	0	0	1
23	0	1	0	0	6	0	0	1	0	0	0	0
23.5	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	10	0	3	18	0	0	5	0	0	2
24.5		0	0		0	0			0			0
25		2	6		0	13			2			0
25.5		0	0		0	0			0			0
26		1	8		0	21			3			1
26.5		1	0		1	0			0			0
27			3		0	16			2			
27.5			0			0			0			
28			0			0			0			
28.5			1			12			1			
29			0			0			0			
29.5			0			0			0			
30			3			4			1			
30.5			0			0			0			
31			1			7			4			
31.5			0			0			0			
32			3			5			1			
32.5			0			0			0			
33			0			3			0			
33.5			0			0			0			
34			2			1			0			
34.5			0			0			0			
35			0			0			0			
35.5			0			0						
36			1			1						
36.5			0									
37			1									
37.5			0									
38			0									
38.5			0									
39												
39.5												
40												
Total number of hours	478	478	478	689	689	689	351	351	351	319	319	319

Appendix C

Monthly Energy Generated (kWh)

15m					
Month	**March**	**April**	**May**	**June**	**Average**
Swift	212.6	375.2	103.2	54.2	186.3
Ropatec WRE.60	737.3	1339.5	357.8	179.5	653.5
Proven WT 6000	1078.7	1952.7	536.2	273.1	960.2
Proven WT 15000	2528.8	4339.1	1240.1	682.3	2197.6
WTI 26-15	1641.6	3097.5	790.5	349.3	1469.7
WTI 29-20	2045.2	3858.9	984.8	435.1	1831.0
Westwind 20	2454.0	4458.8	1189.8	596.3	2174.7
30m					
Swift	320.0	515.1	161.1	95.2	272.9
Ropatec WRE.60	1162.8	1934.2	582.0	326.1	1001.3
Proven WT 6000	1669.8	2792.3	837.5	473.3	1443.2
Proven WT 15000	3600.0	5626.2	1823.3	1138.1	3046.9
WTI 26-15	3239.0	6133.8	1596.9	688.2	2914.5
WTI 29-20	4035.2	7641.7	1989.4	857.4	3630.9
Westwind 20	3871.0	6438.4	1936.4	1083.9	3332.5
80m					
Swift	438.7	670.4	236.0	161.9	376.8
Ropatec WRE.60	1682.4	2585.8	892.3	606.1	1441.6
Proven WT 6000	2542.5	4110.6	1360.1	853.9	2216.8
Proven WT 15000	4653.2	7147.1	2553.7	1749.2	4025.8
WTI 26-15	8552.9	16392.9	4194.4	1868.4	7752.2
WTI 29-20	11599.8	22983.4	5713.5	2327.7	10656.1
Westwind 20	5600.4	8607.7	2969.9	2016.4	4798.6

Appendix D

Economic Appraisal for the Utilisation of Small Turbines to Meet Total Demand

Table F1 Financial Input Information	
Down Payment	
Total Installed cost of wind turbines	£146,232
Total Down Payment for system	£65,804
Amount to be borrowed	£80,428
Loan Information	
Term of Loan	10
Annual Percentage rate for loan	10
Annual Repayment (£)	13089.22
Cost of Energy (p/kWh)	7.33

Table F.2 ECONOMIC ANALYSIS	
Description	
4	Number of Turbines Installed
3046.9	kWh of Generation per turbine per month
146251.2	Annual kWh of Generation for all Turbines
£59,600	Total Cost of Wind Turbines
£11,920	Initial Capital Investment in Wind Turbine
£80,428	Amount Borrowed from Bank
136,847.88	Annual Site Demand (kWh/year)
0.219	Load Factor of the Diesel Generator
127268.53	Emission Savings (kgCO2/year)

Table F.4 ECONOMIC EVALUATION OF WIND TURBINE INVESTMENT

	Principal and Interest Payments for borrowed funds					Wind Turbine kWh Generation		Annual Operating Expenses			
Year	Beginning Principal	Annual Payment	Interest	Ending Principal	Equity Invested (Cash from savings)	Annual kWh Generated	Amount that is used	Operation & Maintenance Expenses	Property Tax & Insurance	Equipment, Reserve, or lease	Annual Total Expenditure
1	£80,428	£13,089.22	£8,042.76	£75,381.14	£65,804	146251.2	146251.2	£1,192.00	£2,071.62	£609.30	**£16,962.14**
2	£75,381.14	£13,089.22	£7,538.11	£69,830.03	£0	146251.2	146251.2	£1,203.92	£2,071.62	£612.35	**£16,977.11**
3	£69,830.03	£13,089.22	£6,983.00	£63,723.81	£0	146251.2	146251.2	£1,215.96	£2,071.62	£615.41	**£16,992.21**
4	£63,723.81	£13,089.22	£6,372.38	£57,006.97	£0	146251.2	146251.2	£1,228.12	£2,071.62	£618.49	**£17,007.45**
5	£57,006.97	£13,089.22	£5,700.70	£49,618.45	£0	146251.2	146251.2	£1,240.40	£2,071.62	£621.58	**£17,022.82**
6	£49,618.45	£13,089.22	£4,961.84	£41,491.07	£0	146251.2	146251.2	£1,265.21	£2,071.62	£625.93	**£17,051.98**
7	£41,491.07	£13,089.22	£4,149.11	£32,550.96	£0	146251.2	146251.2	£1,290.51	£2,071.62	£630.31	**£17,081.66**
8	£32,551	£13,089.22	£3,255.10	£22,716.83	£0	146251.2	146251.2	£1,316.32	£2,071.62	£634.72	**£17,111.89**
9	£22,717	£13,089.22	£2,271.68	£11,899.29	£0	146251.2	146251.2	£1,342.65	£2,071.62	£639.17	**£17,142.66**
10	£11,899	£13,089.22	£1,189.93	£0.00	£0	146251.2	146251.2	£1,369.50	£2,071.62	£643.64	**£17,173.98**
11	£0	£0.00	£0	£0.00	£0	146251.2	146251.2	£1,410.59	£2,071.62	£650.08	**£4,132.28**
12	£0	£0.00	£0	£0.00	£0	146251.2	146251.2	£1,452.90	£2,071.62	£656.58	**£4,181.10**
13	£0	£0.00	£0	£0.00	£0	146251.2	146251.2	£1,496.49	£2,071.62	£663.14	**£4,231.25**
14	£0	£0.00	£0	£0.00	£0	146251.2	146251.2	£1,541.39	£2,071.62	£669.77	**£4,282.78**
15	£0	£0.00	£0	£0.00	£0	146251.2	146251.2	£1,587.63	£2,071.62	£676.47	**£4,335.72**
16	£0	£0.00	£0	£0.00	£0	146251.2	146251.2	£1,651.13	£2,071.62	£686.62	**£4,409.37**
17	£0	£0.00	£0	£0.00	£0	146251.2	146251.2	£1,717.18	£2,071.62	£696.92	**£4,485.72**
18	£0	£0.00	£0	£0.00	£0	146251.2	146251.2	£1,785.87	£2,071.62	£707.37	**£4,564.86**
19	£0	£0.00	£0	£0.00	£0	146251.2	146251.2	£1,857.30	£2,071.62	£717.98	**£4,646.90**
20	£0	£0.00	£0	£0.00	£0	146251.2	146251.2	£1,931.59	£2,071.62	£728.75	**£4,731.96**
Total	£80,428	£130,892.22	£50,464.62		£65,804			£29,096.66	£41,432.40	£13,104.57	**£214,525.84**